

**THE NEW WORLD
OF SCIENCE**

The Century New World Series

W. F. WILLOUGHBY, GENERAL EDITOR

THE NEW WORLD OF SCIENCE

Edited by Robert M. Yerkes

POLITICAL SYSTEMS IN TRANSITION

By Charles G. Fenwick

THE WORKERS AT WAR

By Frank Julian Warne

Other titles will be published later



Figure 11, (CHAPTER XXI, page 387). The Dodge instrument for training gun-pointers

The Century New World Series

A FOOL !
THE NEW WORLD
OF SCIENCE

ITS DEVELOPMENT DURING THE WAR

EDITED BY

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National Research Council

ILLUSTRATED



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PREFACE

In February, 1919, the editor of the Century New World Series invited Dr. George Ellery Hale to prepare for the series a volume on the war and science. This invitation contained the following suggestions:

"It is desirable to give, first, a general statement of the extent to which the successful prosecution of the war required the mobilization of the resources of the country; second, the manner in which such resources came to the aid of the Government; third, the results gained in the fields of research; and, finally, the effect that the war has had and will have on the promotion of scientific research and the application of science to industry in the future. An account, of course, should be given of the organization and work of the National Research Council and the other agencies created by the Government for the handling of scientific phases of the war administration."

Dr. Hale, feeling that it was impracticable for him to prepare the entire volume, requested the writer to arrange with scientific authorities for the preparation of various chapters and to act as editor of the volume. It was originally planned to have manuscripts prepared by a few individuals, each of whom should be responsible for the military contributions of a certain science or group of sciences. This idea could not be put into effect because of specialization in scientific war service. The final outcome was the splitting of major sections of the book into chapters which deal with the special aspects and contributions of physics, chemistry, geology, and other sciences.

The volume is not a complete account of the relations of science in America to military activities; instead it presents examples of the important contributions of several of the

natural sciences and of their related technologies. Completeness of treatment within the scope of such a volume as was proposed was impracticable because of the magnitude and diversity of scientific service. It is appropriate to state also that because of the impracticability of mentioning more than a small percentage of those who deserve recognition, no attempt has been made by most contributors to indicate the credit and responsibility of individuals.

It has been the primary, if not the single, purpose of the several writers to offer to the lay reader an untechnical account of the nature of certain methods and their practical relations to military problems. The editor, and doubtless every contributor, has held clearly in mind the importance of acquainting the public with scientific progress and with typical examples of the dependence of industrial advances upon the development of science.

THE EDITOR.

INTRODUCTION

GEORGE ELLERY HALE

One of the most striking results of the war is the emphasis it has laid on the national importance of science and research. The sharp spur of necessity, felt by the Allies soon after the opening of hostilities, drove them to the instant utilization of scientific research to make good the losses caused by the restriction of imports. Optical glass for gun-sights, range-finders and periscopes; chemicals needed for high explosives; and scores of other products developed in Germany after long years of investigation, were suddenly rendered inaccessible. Some of these could be manufactured without much delay; but in many cases the necessary process was unknown, and could only be discovered by research. Investigators from the universities, the industries and the technical schools were called upon for aid, and manufacture was soon rendered possible.

But the aid thus given was by no means restricted to the duplication of known devices. It shortly became clear that many of the problems of war lie in the domain of the physicist, the chemist, the meteorologist, no less than in that of the military expert. The physicist was quick to recognize that enemy guns, though completely hidden from view by intervening ground, might be accurately located by sound, and apparatus for this purpose was rapidly developed and employed with great success along the western front. The chemist, when retaliation was forced by the German introduction of poisonous gases, developed new and powerful vapors that led the originators of this system of warfare to regret the step they had taken. The meteorologist, from his observation posts along the battle line, supplied the data needed by the gunner, the sound-ranger, the leader of gas attacks, and the airman. The astronomer studied the trajectories of projectiles, improved the

methods of navigating airplanes, and learned how to increase the range of guns and the accuracy of bomb-dropping. The bacteriologist sought out the hidden mechanism of trench fever, and the means of lessening its ravages. And so we might go on, drawing hundreds of typical illustrations from every branch of science.

The bearing of such varied and productive activities goes far beyond the immediate issues of war, and reaches down to the very foundations of national welfare. The problems of peace are inextricably entangled with those of war, and if scientific methods and the aid of scientific research were needed in overcoming the menace of the enemy they will be no less urgently needed during the turmoil of reconstruction and the future competitions of peace.

Remember the case of the aniline dyes, the first of which, mauve, was discovered by Sir William Perkin in 1856. Here, as in so many other instances, a great achievement of British initiative met with no recognition from the home government, and the fruits of Perkin's discovery were gathered abroad. Aniline, from which mauve is derived, is one of the products of coal-tar, formerly regarded as useless waste. Thousands of chemists, thoroughly infused with the spirit of research in the German universities, and supported by great corporations, enjoying the powerful encouragement of the Government, have built upon this foundation the great dye industry of Germany. The basic processes involved in the preparation of the dyes are precisely those required for the manufacture of tri-nitro-toluol and other high explosives. Thus the German government, bent on its preparations for war, quite naturally developed an industry that brought great commercial prosperity and at the same time provided the factories, equipment, and trained chemists necessary to produce thousands of tons of explosives.

Or recall the fixation of nitrogen. Long before the war Germany systematically exploited the cheap water-power of Norway for the manufacture of nitrates, needed alike for powder and for fertilization of German soil, where the output of

wheat was thus raised from 15 bushels to the acre, the average in the United States, to 35 bushels to the acre. The Chilean nitrate beds were far away, and an interruption of overseas traffic would inevitably accompany the outbreak of hostilities. Thus German chemists applied, not merely the electric arc process of nitrogen fixation rendered commercially possible by the waterfalls of Norway, but other processes now effectively utilized on an immense scale within Germany itself. The results, rendered plainly visible during the war by the enormous quantities of ammunition expended along the western front, will be no less important in the economic restoration of the country through intensive agriculture.

Thus the very agencies of war will become powerful factors in the competitions of peace, and the research methods from which they sprang will play a far larger part in the world than ever before.

At the outbreak of the war the statesmen of the Allies were but little concerned with the interests of research. Necessity, as we have seen, soon opened their eyes, and the results so rapidly obtained convinced them that a radical change of policy was essential. Perceiving the enormous advantages derived by Germany from the utilization of science, and with wise anticipation of the needs of the future, they took steps to remedy the earlier neglect of science which the war had rendered so conspicuous. An Advisory Council of Scientific and Industrial Research was set up by the British Government in 1915, and one million pounds was appropriated for the promotion of research in science and the arts. In the face of rapidly rising wages and mounting costs of raw materials, it was seen that the most direct of all possible attacks upon the high cost of living might be made through the agency of research. The cost of electric illumination, for example, will be still higher than it is to-day unless existing methods of generating and using the current can be improved. Thus the recent production of an incandescent lamp, which yields equal light with a fraction of the current, is a most important step in

the right direction. In similar ways costs can be reduced and efficiency increased in all directions through the intelligent use of scientific research.

The recognition of this fact throughout the British Empire has resulted in a world-wide movement of great significance. Advisory Councils for Scientific and Industrial Research, having large government appropriations at their disposal, have been established by Australia, Canada, South Africa, and New Zealand, and provision is being made for large research laboratories to render possible investigations in all branches of science, and in engineering, medicine, and agriculture. It is universally recognized that the underlying problems of science, from the solution of which all great industrial advances spring, must be attacked no less vigorously than the more obvious practical questions. Therefore this movement, the most significant and far-reaching in the history of science, recognizes no distinction between the problems of science and those of the arts, but seeks to provide broadly and liberally for the advancement of knowledge and its effective application for the public welfare.

The fundamental importance of science has long been recognized by the ablest leaders of industry in the United States. The telephone was born in a research laboratory, and as soon as the American Telephone and Telegraph Company was formed, this laboratory was made into a department of its activities. Under the far-seeing guidance of Theodore N. Vail it has now become the Department of Development and Research under Vice-President John J. Carty, employing thirteen hundred scientists and engineers who devote their time exclusively to research and development in the telephone art. Two of the outstanding results of this laboratory are trans-continental telephony by wire and wireless telephony between airplane and earth and between earth stations as widely separated as Arlington and Hawaii. The General Electric Company, which also grew out of research, maintains a great research laboratory, costing nearly a million dollars per year,

under the energetic and effective leadership of W. R. Whitney. If the scores of devices and improvements that have flowed from this laboratory were restricted merely to the Mazda lamp, this country would have gained greatly by its establishment. In another field George Eastman, recognizing that photographic materials and methods are susceptible to great improvement, founded in 1912 the Research Laboratory of the Eastman Kodak Company, where C. E. K. Mees and his associates are accomplishing many important advances. One might go on to mention many other successful laboratories of industrial research in this country, including those of Thomas A. Edison, the Westinghouse Electric and Manufacturing Company, the Goodyear Tire and Rubber Company, the United States Steel Corporation, the General Chemical Company, the General Bakelite Company, and others of equal importance. A notable case is the research laboratory of the du Pont de Nemours Company, which began with six chemists in 1902, and employed three hundred chemists in 1918, when its annual expenditure had reached three million dollars.

While the prime objects of these laboratories is the direct solution of problems arising in the industries, much research for the advancement of science is done in them, and their directing heads are constantly emphasizing the importance of fundamental science and its development. Thus W. R. Whitney has said:

“Necessity is not the mother of invention; knowledge and experiment are its parents. This is clearly seen in the case of many industrial discoveries; high-speed cutting tools were not a necessity which preceded, but an application which followed the discovery of the properties of tungsten-chromium-iron alloys; so, too, the use of titanium in arc lamps and of vanadium in steel were sequels to the industrial preparation of these metals, and not discoveries made by sheer force of necessity.”

One of the best illustrations of the practical importance of researches made solely for the purpose of increasing knowledge

is afforded by the development of wireless telegraphy. The now familiar electric waves, transmitted by the ether with the velocity of light, were foreshadowed by Faraday and Henry and definitely made known by the mathematical investigations of Maxwell about the middle of the nineteenth century. Nearly forty years later Hertz, deliberately following Maxwell's lead, produced and detected these waves experimentally. Crookes foresaw their possible utilization for wireless telegraphy, which was accomplished over short distances by Lodge in 1894, and applied on a commercial scale by Marconi in 1896.

The wireless telephone was a later development of the pioneer work of Maxwell and Hertz, reënforced by much additional physical research on electric discharges in vacuum tubes and other laboratory phenomena. Similarly the invention of the telephone goes back to the principles of magnetic-electric induction discovered by Faraday; the anti-toxin treatment of disease grew out of Pasteur's investigations of bacteria, which resulted in their turn from his studies of the nature of certain crystals, made for the sole purpose of advancing knowledge; the airplane had its origin in Langley's researches on the resistance of the air to moving bodies. Analyze any invention, and it will be found that it was rendered possible by the work of men concerned only with the advancement of science. How clearly this is appreciated by the chief leaders of industry is best expressed in the words of Carty, from his presidential address to the American Institute of Electrical Engineers in 1916.

"It was Michael Faraday, one of the greatest of the workers in pure science, who in the last century discovered the principle of the dynamo electric machine. Without a knowledge of this principle discovered by Faraday the whole art of electrical engineering as we know it today could not exist and civilization would have been deprived of those inestimable benefits which have resulted from the work of the members of this Institute.

"Not only Faraday in England, but Joseph Henry in our own country and scores of other workers in pure science have laid the

foundations upon which the electrical engineer has reared such a magnificent structure.

"What is true of the electrical art is also true of all the other arts and applied sciences. They are all based upon fundamental discoveries made by workers in pure science, who were seeking only to discover the laws of nature and extend the realm of human knowledge.

"By every means in our power, therefore, let us show our appreciation of pure science and let us forward the work of the pure scientists, for they are the advance guard of civilization. They point the way which we must follow. Let us arouse the people of our country to the wonderful possibilities of scientific discovery and to the responsibility to support it which rests upon them and I am sure that they will respond generously and effectively."

In each of the illustrations we have cited, and in many others like them, three elements, fundamentally important to the welfare of the United States, should be recognized. It is clear that a nation anxious to reduce the cost of living and unwilling to give place in the industrial world to better informed rivals must adopt every feasible means of promoting research in the industries. It is equally clear that so long as the security of the world is menaced by unscrupulous military powers, research methods must be effectively utilized in perfecting the means of national defense. But more fundamental still is the prime necessity, clearly appreciated and strongly emphasized by the far-sighted leaders of American industry, of promoting research in all branches of science, without thought of any industrial application, for the sake of advancing knowledge. As Sir Joseph Thomson has recently said, it is only in this way that the greatest advances are made. The pioneers of industrial research are those who seize and apply the discoveries of men of science, by whom new territories are opened and explored. Without the knowledge derived from such explorations, the investigator bent upon immediate industrial advantage could make little progress.

Our place in the industrial world, the advance of our commerce, the health of our people, the output of our farms, the

conditions under which the great majority of our population must labor, and the security of the nation will thus depend, in large and increasing measure, on the attention we devote to the promotion of scientific and industrial research. The purpose of this book is therefore to describe the part played by science in the war with special reference to the future development and utilization of research on a scale commensurate with the needs of the United States.

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**THE
NEW WORLD OF SCIENCE**



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I

SCIENCE AND WAR¹

GEORGE ELLERY HALE

SCIENCE UNDER NAPOLEON

THIS is by no means the first war in which men of science have been called from their customary researches to solve military problems. For early examples we might go back to the Greeks, and cite illustrations from the conquests of Alexander the Great or the reputed exploits of Archimedes at the siege of Syracuse. But a more striking and illuminating example, of great significance because of the emphasis laid on the national importance of science and research by the leaders of France, may be taken from the history of the French Revolution and the life of Napoleon Bonaparte.

At the period of the French Revolution the Paris Academy of Sciences occupied an unrivalled position in Europe. Composed of the leaders of science in every field, it was therefore prepared to deal with the heavy problems which grow out of a great emergency. When the Convention decided to raise a large army to resist invasion and stamp out civil war, equip-

¹ For the material used in the first half of this Chapter the writer is chiefly indebted to Maindron's *L'Académie des Sciences* and to the Presidential address of M. Guignard at the last annual meeting of the Academy (*Comptes Rendus*, December 22, 1919).

ment of all kinds was lacking. Steel, nitrates and many necessary raw materials were cut off by the blockade, and the nation was thrown upon its own resources.

In this critical situation the Committee of Public Safety appealed to the members of the Academy and their assistants. A chateau at Meudon was placed at their disposal, together with the adjoining park for experimental purposes. Aided by Vandermonde and Berthollet, Monge discovered the process of manufacturing steel and making guns. Fourcroy succeeded in separating copper from bell metal. Vandermonde was placed in charge of the manufacture of rifles, swords, and bayonets. Arms were soon available, but powder was so scarce that Hoche, in command of the army of the Sambre and Meuse, was compelled to retreat for lack of sufficient supply. But the chemists were equal to the emergency, and nitrates were produced from many sources, the former slow methods of manufacturing explosives were replaced by new ones and in a short time a single factory was turning out powder at the then extraordinary rate of 30,000 pounds per day. Potash, formerly imported from Spain, was also cut off, but a supply was obtained from the ashes of plants. New methods were devised for the rapid tanning of leather, the manufacture of paper, and scores of other products. Even more striking to the popular imagination was the development of the "telegraph" or long distance signaling device of the Abbe Claude Chappe and the war balloon of Guyton de Morveau. If to the unthinking all these results of science seemed to be creations of the moment, those who paused to reflect saw their origin in the decades of research that preceded the Revolution and reached their height in Lavoisier, who fell a victim to the guillotine.

In the events thus briefly sketched we have an exact parallel to the experiences of the present war, which once more forced national leaders when confronted by critical problems, to seek at the last moment the aid of science. A much more enlightened appreciation of the value of science to the state was shown by Napoleon Bonaparte, whose relations with the Paris Acad-

emy of Sciences are of special interest at a time when an equal grasp by our own Government of the possibilities of research, embodied in concrete form and applied to national advancement, would bring a great return.

The brilliant strategy displayed in his Italian campaign, and the attitude which he assumed toward the men of science of the conquered territory, led to Napoleon's election as a member of the National Institute of France on December 25, 1797. In his letter of acceptance he remarks:

... "The truest conquests, the only ones that give rise to no regrets, are those gained over ignorance.

"The most honorable as well as the most useful activity of nations is to contribute to the advancement of human knowledge.

"The real strength of the French Republic should henceforth lie in its determination to possess every new idea, without a single exception."

Entering at once upon his duties, Napoleon took part with Borda and Coulomb the physicists, Laplace the astronomer, and other members in the examination of devices, some of them of a military nature, submitted for the consideration of the Institute. But his belief in the utilization by the state of the services of men of science was most strikingly demonstrated in the organization of his expedition to Egypt. In addition to the military and naval contingents, he took with him a scientific commission, comprising many of the most distinguished scholars of France. The long list of members includes mathematicians, physicists, astronomers, chemists, engineers, geologists and mineralogists, botanists, zoologists, surgeons, pharmacists, political economists, archeologists, architects, painters, and many others. Less than a month after his arrival in Cairo, Napoleon established the Institute of Egypt, modeled after the Institute of France, with which it was in close correspondence. As Vice-President of the Institute of Egypt, and in constant attendance at its meetings, Napoleon called for the appointment of committee after committee, to

report on the best means of baking bread for the army, the discovery of a substitute for hops needed in the manufacture of beer, the best method of purifying the water of the Nile, the relative efficiency of wind-mills and water-mills, the possibility of manufacturing powder in Egypt. By no means forgetful of the wider interests of science and the arts, Napoleon secured the appointment of a committee to report on the feasibility of establishing an astronomical observatory in Egypt, and permanently preserved, in the magnificent volumes of the *Description de l'Egypt*, the exhaustive studies of the temples and antiquities made by his architects and archeologists. It is interesting to remember that it was Napoleon who announced to the National Institute, a few days after his return to Paris, that he had given orders to bring to France the celebrated Rosetta Stone, with its tri-lingual inscription, which enabled Champollion some years later to decipher the Egyptian hieroglyphs. Thus the title "Le membre de l'Institut, Général en chef," invariably used by Napoleon throughout his Egyptian campaign, was fairly descriptive of his double service. Indeed, when we recall the early collapse of that ill-fated expedition, we cannot fail to recognize that his contribution to science and the arts as Member of the Institute was far more enduring than his initial military success as Commander in Chief at the Battle of the Pyramids.

During the triumphs of his subsequent career Napoleon gave strong support to the National Institute of France, which then attained a brilliancy of success and achievement without a parallel in the history of science. In 1800, as First Consul, Napoleon presided over the meetings of its Class of Physical and Mathematical Sciences (corresponding to the present Academy of Sciences), and after listening to an address by Volta on his electrical researches, proposed that a medal be awarded him for his discoveries, which was done without delay. Soon afterwards, deeply impressed by the great possibilities which he keenly perceived to lie in the future development of similar researches, Napoleon established a medal

valued at three thousand francs to be awarded to the author of the best experiment made each year in the field of galvanic electricity. Moreover, "with the special object of encouraging and fixing the attention of physicists on that branch of physics which, in my opinion, is the pathway to great discoveries," he announced his intention to present the sum of sixty thousand francs "to any one whose experiments or discoveries, in the judgment of the First Class of the Institute, shall accomplish an advance in electricity or galvanism comparable to that made by Franklin and Volta."

Subsequently, both as First Consul and as Emperor, Napoleon continued to take personal part in the work of the Institute, which he regarded as one of the most important national agencies for the advancement of France. He provided for its reorganization with enlarged scope and greater powers (law of January 23, 1803) and established it, at the expense of the state, in the Palais des Quatre-Nations (now Palais de l'Institut). He presented to the Institute a large number of statues of eminent men of science and letters formerly in the Louvre, and subsequently added a statue of d'Alembert "as a mark of his esteem for the Institute and of his constant wish to reward and encourage the labors of this company, which contributes so largely to the prosperity and welfare of his people." He called upon the Institute to report every five years on the progress of science, the arts and letters in France. He founded a series of thirty-five grand prizes, nineteen of ten thousand francs each, sixteen of five thousand francs each, to be allotted by the Institute and awarded every ten years by the Emperor in person for researches and inventions in the various branches of science and the arts. In short, up to the time of his abdication Napoleon did everything in his power to advance the interests of the Institute and to render it of the greatest service to the nation. He was amply rewarded by the successes of its members, best illustrated by the accomplishments of such men as Laplace, Lagrange, Berthollet, Cuvier, Coulomb, Biot, Delambre, Jussieu, and Fourier, who, with

others of like distinction, constituted the most brilliant company of investigators ever assembled.

We have permitted this brief account of science in France during the period of Napoleon to develop beyond the immediate questions of war because of the value of the example from our present point of view. In fact, as shown in the introductory chapter, it is impossible to distinguish sharply between science as needed for national defense and science as the basis of industrial progress. It will be fortunate indeed if the heavy blows to civilization directly chargeable to the Central Powers can be offset in some degree by the new appreciation of science, and advantage should be taken of every feasible method of stimulating research that may be suggested by past experience.

SCIENCE IN THE CIVIL WAR

Let us now glance for a moment at the early development of science in the United States, and observe the part it played in the Civil War. De Tocqueville, who visited this country in 1831, has preserved his impressions in his well-known work on "Democracy in America." In a chapter entitled "How the example of the Americans fails to prove that a democratic people cannot possess aptitude and taste for science, literature and art," he wrote as follows: "It must be admitted that among the civilized peoples of our time there are few in which the higher sciences have made less progress than in the United States." This he attributed to our Puritan origin, our pursuit of the wealth which is so easily acquired in a new country, and our dependence upon England for intellectual things. "I consider the people of the United States as that portion of the English people which is charged with the exploitation of the forests of the new world, while the rest of the nation, enjoying more leisure and less preoccupied with the material needs of life, may devote itself to thought and to the development of the human mind in every field."

But although he regarded the United States as exceptional, he fancied that he recognized in all democracies conditions of

disturbance and unrest which leave little opportunity for the quiet and repose essential to the cultivation of science. These he carefully distinguished, however, from great upheavals of the body politic. "When a violent revolution occurs among a highly civilized people, it cannot fail to give a sudden impulse to feeling and imagination." Thus, he pointed out, the French achieved their highest development in science soon after the revolution of 1789.

In 1863, when the National Academy of Sciences was incorporated, de Tocqueville would probably have considered our intellectual dependence upon England to be materially less than at the time of his visit to the United States, thirty years earlier. Doubtless he would have attributed the improved condition of American science to the effect of the Civil War, and the considerable increase in wealth and leisure. In 1873, if we may judge from Tyndall's remarks in the concluding lecture of his American series, European opinion saw hope for the future of science in the United States, but recognized few important accomplishments. "If great scientific results are not achieved in America, it is not to the small agitations of society that I should be disposed to ascribe the defect, but to the fact that the men among you who possess the endowments necessary for profound scientific inquiry are laden with duties of administration, so heavy as to be utterly incompatible with the continuous and tranquil meditation which original investigation demands." At this time Henry was secretary of the Smithsonian Institution, Barnard was president of Columbia College, and Rogers was president of the Massachusetts Institute of Technology. There was thus some justification for Tyndall's remark, though the amount of scientific research in progress was much larger than one would infer from his statement of the case. Moreover, though deprived by other duties of the privilege of personal work in the laboratory, these very men, charter members of the National Academy, had assisted in laying the foundations of science in America.

One of the most striking pen portraits of President Lincoln

that we possess depicts him on the great tower of the Smithsonian Institution, which he ascended night after night with Joseph Henry, during the Civil War. From this vantage point lights were flashed to distant stations, in connection with tests of new methods of signaling. It was in such researches for military purposes that the National Academy of Sciences had its origin.

The period of these experiments was an anxious one. Many months of war, marked by serious and unexpected reverses, had left small room for over-confidence, and taught the necessity of utilizing every promising means of strengthening the northern arms. With one or two notable exceptions, the great scientific bureaus of the Government, now so powerful, had not come into existence. But the country was not without its leaders of science and engineering, both within and without the Government circle. Davis, fighting Admiral, Chief of the Bureau of Navigation, and founder of the Nautical Almanac; Bache, Superintendent of the Coast Survey, and designer of the defenses of Philadelphia; and Joseph Henry, of whom we have already spoken, clearly recognized the need of a national organization, embracing the whole range of science, to advise the Government on questions of science and art. Joining with them Louis Agassiz, the great naturalist; Benjamin Pierce, mathematician and astronomer; and B. A. Gould, founder of the Observatory of the Argentine Republic, they planned the National Academy of Sciences. A bill to incorporate the Academy was introduced in the Senate by Senator Wilson of Massachusetts on February 21, 1863. This passed the Senate and the House, and was signed by President Lincoln on March 3. After enumerating the charter members, who comprised the leading men of science and engineers of the day, and empowering the Academy to make its own organization, the bill provides that "the Academy shall, whenever called upon by any department of the Government, investigate, examine, experiment and report upon any subject of science or art, the actual expense of such investigations, examinations, experi-

ments, and reports to be paid from appropriations which may be made for the purpose; but the Academy shall receive no compensation whatever for any services to the Government of the United States."

As the adviser of the Government on questions of science, the Academy was immediately called upon by the War and Navy Departments to report on various problems connected with the war. Among these reports the following may be mentioned:

On the Protection of Bottoms of Iron Vessels from Corrosion.

On the Adjustment of Compasses to Correct Magnetic Deviation in Iron Ships.

On Wind and Current Charts and Sailing Directions.

On the Explosion on the United States steamer *Chenango*.

On Experiments on the Expansion of Steam.

On the Preservation of Paint on Army Knapsacks.

In addition to such formal reports from special committees, many members of the Academy contributed individually to the study of war problems. Thus we find in the early records the titles of such papers as the following:

F. A. P. Barnard: On the force of fired gun-powder and the pressure to which heavy guns are actually subjected in firing.

Joseph Henry: On materials for combustion of lamps in lighthouses.

J. E. Hilgard: On a chronograph for measuring the velocity of projectiles.

J. E. Hilgard: Note on the changes that have taken place in the bar of Charleston Harbor since the sinking of obstructions in the main channel.

B. A. Gould: Various papers on the stature, proportions, ages, and vision of American soldiers.

W. H. C. Bartlett: On rifled guns.

Most of the work of the members on war problems was, of course, not embodied in published papers, though it formed an important part of the activities of the Government.

This illustration of a national organization of science, including representatives of the army, navy, and civil branches of the Government, coöperating closely with the men of science in civil life, recalls the similar organization in France under Napoleon. Since the Civil War the National Academy has been called upon by the President, by Congress, and by the heads of Government departments to deal with many scientific problems, of the most diverse nature. A new opportunity for national service, which arose with the German menace, was recognized and acted upon nearly a year before the United States entered the present war.

II

WAR SERVICES OF THE NATIONAL RESEARCH COUNCIL

GEORGE ELLERY HALE

BROADLY speaking, the organizations of scientific men effected in this country and in Europe under the influence of the war were of two classes: (1) those temporarily constituted, either as separate groups or as parts of existing branches of the army or navy, to deal with military, naval, or industrial problems: and (2) those permanently established for the promotion and development of scientific and industrial research. They therefore correspond to the two general effects that such a war must inevitably produce in unprepared countries, the Governments of which have lacked adequate appreciation of the national value of science: A sudden demand for military and naval equipment of new types and for products formerly imported from enemy countries, and an almost equally sudden recognition of the fact that science and research must henceforth be recognized and developed as national assets of the first importance.

It is obviously impossible within the limits of this book to describe the work of these numerous organizations or even to mention their names, though some typical illustrations of their activities may be found in subsequent chapters. It is to be hoped that adequate reports will be published of the work of such bodies as the Naval Consulting Board and others, both military and civil, that played a prominent part in the war. When temporarily constituted, their history forms an important part of the war record. But when permanently estab-

lished, to deal during the war with its special problems, and later to promote the broad interests of scientific and industrial research, they call for special consideration, because of the important bearing of their war activities on those to be undertaken under peace conditions. In the United States the national body of this character is the National Research Council, formed by the National Academy of Sciences at the call of the President.

In April, 1916, when the wanton attack on the *Sussex* had greatly increased the tension of our relations with Germany, the Academy voted unanimously to offer its services to the President of the United States. He accepted this offer immediately, and expressed the desire that the Academy should bring into coöperation governmental, educational, industrial, and other research agencies, primarily in the interest of the national defense, but with full recognition of the duties that must be performed in the furtherance of scientific and industrial progress.

The Academy's connection with the Government, its inclusion of the whole range of science, and its many years of coöperation with the Royal Society of London, the Paris Academy of Sciences, and other similar institutions abroad, pointed to it as the only body in the United States in a position to comply with the President's request. It was clear, however, that membership in the desired organization should not be exclusively confined to the National Academy. Many technical bureaus of the army and navy, for example, should be represented by their chiefs ex-officio, and in other cases a varied membership, broadly representative of research in its numerous aspects, would also be desirable. The Organizing Committee accordingly proposed the establishment of a new body, resting legally upon the charter of the Academy, sharing its privileges, both at home and abroad, and at the same time affording the wide freedom of selection desired.

The National Research Council, comprising the chiefs of the technical bureaus of the army and navy, the heads of gov-

ernment bureaus engaged in scientific research, a group of investigators representing educational institutions and research foundations, and another group including representatives of industrial and engineering research, was accordingly constituted by the Academy with the active coöperation of the leading scientific and engineering societies. The important part taken by the Engineering Foundation, which voted to apply its entire income for the year toward the expense of organization, to give the services of its Secretary, and to provide a New York office for the Research Council, is a noteworthy illustration of the cordial support given by the engineers.

On July 24, 1916, President Wilson addressed the following letter to the President of the National Academy:

WASHINGTON, D. C., July 24, 1916.

Dr. William H. Welch,

President of the National Academy of Sciences, Baltimore,
Maryland.

MY DEAR DR. WELCH: I want to tell you with what gratification I have received the preliminary report of the National Research Council, which was formed at my request under the National Academy of Sciences. The outline of work there set forth and the evidences of remarkable progress towards the accomplishment of the object of the Council are indeed gratifying. May I not take this occasion to say that the Departments of the government are ready to coöperate in every way that may be required, and that the heads of the Departments most immediately concerned are now, at my request, actively engaged in considering the best methods of coöperation?

Representatives of government bureaus will be appointed as members of the Research Council as the Council desires.

Cordially and sincerely yours,

(Signed) WOODROW WILSON.

An Executive Order, requesting the National Academy to perpetuate the National Research Council, defining its duties, and providing for the coöperation of the Government, was subsequently issued by the President.

The National Research Council was formally organized at a meeting held in the Engineering Societies Building in New York on September 20, 1916. The United States had not yet broken relations with Germany, but some important steps, looking toward preparation for war, could be taken without delay. A national census of research, including data regarding the equipment for research, the men engaged in it, and the lines of investigation pursued in coöperating Government Bureaus, educational institutions, research foundations, and industrial research laboratories, was taken by a Research Council Committee under the Chairmanship of the Director of the Bureau of Standards. With the coöperation of leading national scientific societies, committees were formed for the three-fold object of strengthening the national defense, developing American industries, and advancing knowledge. Steps were taken to secure the appointment of Research Committees in educational institutions, where many problems relating to the national defense were subsequently investigated. A strong committee was established for the promotion of industrial research, and comprehensive plans were made with the view of securing a far wider recognition of the value of research in the development of American industries.

However, relations with Germany grew rapidly worse, finally resulting in war. On February 28, 1917, the Council of National Defense passed a resolution expressing its recognition of the fact that the National Research Council, at the request of the President, had undertaken to organize the scientific resources of the country in the interest of national welfare, and inviting the Council to coöperate with it in matters pertaining to scientific research for national defense. Soon afterwards, the Research Council was requested to act during the war as the Department of Science and Research of the Council of National Defense. As war approached, the Research Council opened offices in Washington and prepared to give its entire attention to military and naval problems, and to industrial problems developed by our entrance into hostilities.

Two lines of effort, demanding very different modes of procedure, lay before the Council in entering upon its war services. Many new scientific methods, unfamiliar in the United States, had been developed and successfully applied by our Allies during the war. It was a matter of the first importance that we should lose no time in profiting by such advantages, which demanded for their application the organization of new services in the army and navy, and the enlistment of large numbers of scientific men for service at home and in the field. In the second place, experience abroad had shown the necessity of conducting researches for the solution of military, naval, and industrial problems, even after war had begun. It goes without saying that such researches, which demand much time and thought, should have been initiated years before the outbreak of war. But as preparedness for national defense had been as sadly neglected in its scientific aspects as on its more obviously military side, there was no alternative. In Germany, where a short war had been expected, the men of science had been called upon after the outbreak of hostilities to develop new processes and to provide substitutes for commodities cut off by the blockade. In France and England, researches conducted under the disturbing conditions of war had been equally successful. It was plain that we in the United States must lose no time in taking advantage of our great national asset of scientific men and laboratories.

At this point a fundamental principle in the policy of the National Research Council should be mentioned. In spite of its establishment for the promotion and utilization of scientific research, the Council took the stand from the outset that in time of war the proper procedure is to adopt and immediately to utilize at the front the best available military device for the accomplishment of any purpose in view, before attempting to develop a more effective means of serving the same end. When men and means were available, researches for the improvement of such devices, or for the development of new ones, might advantageously be initiated in many cases, but there

could be no excuse for delaying action in order to await the outcome of these researches. In time of war there can surely be no justification for delays due to a desire to gratify personal or national pride in inventiveness or originality.

When a scientific investigator undertakes any piece of research, his first act is invariably to ascertain just what work has already been accomplished in that field. It goes without saying, therefore, that an organization composed of scientific investigators must proceed in the same way in attacking any large problem involving research. Moreover, it must lose no time in arranging for close coöperation with the scientific men of other nations concerned with the same problem.

Accordingly, the President of the National Academy, accompanied by the Chairman of the Committee appointed by the Academy to organize the Research Council, made a preliminary visit to England and France in August, 1916, in order to learn the general character of the war services rendered by the scientific men of these countries. They found the investigators, with whom they had coöperated for many years in scientific research, actively engaged in the study of war problems. Eminent physicists, always successful in research and prolific in new ideas, were giving much attention to the improvement of airplanes, which were so greatly increased in efficiency in England during the war. Others were attacking the submarine problem, the full menace of which has finally become known to the public through the recent articles of Admiral Sims. The Astronomer Royal, most of whose staff was at the front, was utilizing the facilities of the Royal Observatory at Greenwich for the rating of chronometers and the adjustment of field-glasses. On the roof was a range-finder for the location of Zeppelins and German airplanes, which had recently dropped bombs in the Observatory garden. Distinguished physiologists were seeking means of alleviating the new sufferings imported by the Huns into warfare. In fact, all British men of science, if unable to enlist for duty at the front, were devoting themselves to any available war service.

In France the activities of the men of science, who responded to the earliest call for the national defense, were no less impressive. The Minister of Public Instruction, himself an able mathematician and member of the Institute, had organized a strong group, which dealt with a great number of war problems. Some of its members were the first to conceive and to carry into effect the method of sound-ranging, a brilliant application of physics in warfare. Leading physicists and astronomers with whom American investigators had long been associated in the work of the International Union for Coöperation in Solar Research, were prominent members of this group. The Paris Academy of Sciences was also contributing largely through its members toward the solution of scientific questions of both military and industrial importance. Such examples afforded a powerful stimulus to those American investigators who felt that the continued lawlessness of the Germans must soon identify our interests with those of the Allies.

On the day preceding the entrance of the United States into the war, the following cablegram was sent by the National Academy of Sciences to the Royal Society of London, the Paris Academy of Sciences, the Accademia dei Lincei of Rome, and the Petrograd Academy of Sciences — leading scientific bodies, then engaged in the study of war problems, with which the National Academy had coöperated for many years in scientific research.

The entrance of the United States into the war unites our men of science with yours in a common cause. The National Academy of Sciences, acting through the National Research Council, which has been designated by President Wilson and the Council of National Defense to mobilize the research facilities of the country, would gladly coöperate in any scientific researches still underlying the solution of military or industrial problems.

Steps were also taken to despatch a group of seven scientific investigators to France and England for the study of war problems and the arrangement of effective means of coöperation.

The members of the Committee sailed early in May, 1917, and were most cordially welcomed and given information of great value.

The response of our foreign colleagues to our offer of co-operation was immediate and effective. France sent to the United States an able group of investigators, and both England and Italy did likewise. The French members brought with them a large collection of instruments and devices developed in France for military and naval purposes since the outbreak of the war, which was invaluable in connection with our work.

Just at this time the submarine danger was at its height. Shipping to the amount of 900,000 tons was sunk by the Germans in April, 1917, and the British Government was extremely doubtful whether this menace, the most serious of the war, could be overcome. As Admiral Sims has recently pointed out, quick action was essential. The depth charge had already been invented, and naval officers all agreed that if the submarine could be definitely located it could be easily destroyed. Thus the problem for the scientific investigator was to devise a means of determining the exact position of a submerged submarine. While it was true that the results of their researches might not be obtained and applied in time, it was equally clear that no effort should be spared, even at that late date, to devise the apparatus so urgently required. If the vigorous action of the combined navies of the Allies should succeed in alleviating the menace, without wholly overcoming it, there might be time to develop a detection method which would permit the finishing blow to be dealt. Fortunately for the cause of the Allies, the convoy system, then regarded by the masters of merchant ships as impracticable, was soon successfully applied. But this outcome could not be foreseen, and the men of science were in duty bound to contribute their best efforts without delay.

The National Research Council accordingly organized a conference on the submarine problem in which the foreign repre-

sentatives, with officers of the Navy Department, and the physicists and engineers who had already studied the question in this country, participated.¹ In order to make clear the general nature of the methods discussed, the following brief description of the apparatus employed may be of service.

Submarine detection devices are of two principal classes: listening apparatus, on the principle of the microphone or the stethoscope, and instruments analogous to searchlights for use under water, in which the beam of light is replaced by a beam of sound. A simple physician's stethoscope, if placed under water and connected to the ear by tubing, will render audible the sound from a rapidly moving submarine at a distance of a mile or more. Indeed, a small piece of rubber tubing, if substituted for the stethoscope, will serve very well as a sound detector. By connecting with the ears two stethoscopes, at opposite ends of a supporting bar three or four feet long, the direction of a moving submarine can be determined with considerable accuracy by rotating the bar in a horizontal plane and utilizing the same binaural discrimination with which we ascertain the direction of sounds without apparatus. By refining this apparatus, it is even possible to employ it on a submarine destroyer moving at a speed of several knots, in spite of the local sounds due to the destroyer. However, the method is seriously limited in actual practice; it cannot be used on vessels moving at high speed, it cannot detect submarines lying at rest or moving at low speed, and confusion may result from the presence of several surface vessels, as in the case of a convoy.

We therefore look for assistance to an entirely different device. A beam from a searchlight is quenched by a short thickness of water, but a beam of high frequency sound waves

¹ Three able groups of investigators were already at work on this question in the United States under the Bureau of Steam Engineering of the Navy, and both the Naval Consulting Board and the National Research Council had taken part in promoting studies of the submarine problem.

can penetrate water to a great distance. Soon after the loss of the *Titanic*, an English inventor was granted patents for his method of detecting objects above and below water by the echo of beams of sound, ranging in frequency from 5,000 to 100,000 complete vibrations per second. The method was not carried into practical effect at that time, but during the war the same principle was applied by French and British men of science, and important progress resulted. Before the end of the war this device had been developed to such a degree as to enable a destroyer to detect and run down a submarine more than a mile away.

After a two days' discussion of such methods by the Submarine Conference, it became clear that a greatly intensified attack on the problem of detection should be made. The Research Council accordingly brought to Washington more than forty leading physicists, and a second conference, of several days' duration, was held with the foreign naval officers and men of science. This resulted in the selection of several groups of investigators to take up the problem at a point in its development already attained here and abroad, and to continue its study in coöperation with a special board appointed by the Secretary of the Navy, on which the National Research Council was represented. A more complete account of this work, which involved the organization of special investigations in laboratories in many parts of the country, may be found in Chapter 3.

An important extension of the duties of the National Research Council occurred in July, 1917, when it was requested by the Chief Signal Officer of the army to organize the Division of Science and Research of the Signal Corps. A vice-chairman of the Council was commissioned in the army and placed in charge of this Division, which was given offices in the building of the National Research Council in Washington, where the Division undertook the solution of numerous problems of military importance. Here it was a question both of the immediate application of new scientific methods developed during the

war and the solution by research of outstanding problems. Both of these phases of the work of the Division, including the organization of the Sound-Ranging and Meteorological Services of the Army, and the development and application of improved methods of photography from airplanes, are described in subsequent chapters by those who took part in the work.

A glance through the third annual report of the National Research Council, which briefly surveys the war activities of its many Divisions, occupied with every branch of science, and with engineering, medicine, and agriculture, will indicate the impossibility of giving in this chapter more than a few illustrations of the work performed. In nearly all cases the chief purpose in view was to bring into a coöperating group the men dealing with different aspects of a problem. A good case in point is the work of the Committee on Explosives, authorized by the Secretaries of War and Navy for the purpose of surveying current investigations on explosives, bringing useful information to the attention of the proper military and naval authorities, and arranging for the prosecution of supplementary investigations by governmental, industrial, or other research agencies. (See Chapter 9.) The extensive work of the Committee on Nitrate Investigations, appointed at the request of the Secretary of War, and described in Chapter 8, is another good illustration of the war researches organized by the Council. If space permitted, much might be said of the researches organized under the Chemistry Division, which covered a very wide range, from the preparation in university laboratories of rare drugs and other chemicals rendered scarce by the war, to the study of the physical properties of toxic liquids and explosives, and of methods for combating toxic gases. Committees studied the potash needs and resources of the United States, and the availability of phosphoric acid for plant food; the rubber content of certain California shrubs and the preparation for the Quartermaster's Department of specifications and tests for rubber compounds; the production

of a better fuel for airplane motors, and the causes and remedies of the low efficiency of carburetors; the location and purchase or loan of apparatus required by the Government; the sources of ceramic war materials; the preparation of courses in chemistry, combustion and fuel engineering and a special war curriculum in ceramic engineering for use by the Students Army Training Corps; the waterproofing of fabrics; the preparation of standard specifications for glues and gelatines. Most of these activities, and many others of the most varied nature, were undertaken at the request of various branches of the Government.

The response of American engineers to the numerous demands of the war was quick and effective, and thousands of them saw service at home and abroad. The manufacture of munitions of every kind and the erection of new plants for war purposes absorbed great numbers of engineers in this country, and in France their activities were even more varied. In the work of the Research Council they also played a prominent part, and the coöperative investigations set on foot by the Division of Engineering to meet war needs are being continued and expanded in all directions.

One of these, which led to the development of a helmet of remarkable qualities, enlisted the joint efforts of men of the most diversified experience. An authority on arms and armor, familiar with the practice of all ages, applied his knowledge to the design of the helmet. A distinguished metallurgist specified the composition of the special steels employed, and tested the models by machine gun fire. Associated with them were able engineers and metallurgists, competent to deal with every aspect of the question. Another metallurgical problem arose from faulty procedure in making and forging the steel ingots used in the manufacture of shells, cannon, crank-shafts, etc. Flaws resulted from the inexperience of manufacturers hastily called upon to supply an overwhelming demand, and the consequent rejection of the forgings appreciably delayed our war preparations. How this difficulty was overcome is described

in Chapter 14. Another means of improving the quality of steel has been supplied by the development of a pyrometer suitable for measuring the temperature of steel baths in furnaces. One of the most important of the metallurgical problems attacked was that of the fatigue phenomena of metals. The results of this investigation show that the elevation of the elastic limit of steel, caused by such processes as cold rolling and wire drawing, is dissipated by the repetition of a wide variation of stresses, as in aircraft crank-shafts, which may ultimately break down from this cause.

The development of certain war inventions was another important function of the Engineering Division. A staff of designers and draftsmen, starting in some cases with well-defined schemes and in others with very nebulous suggestions, worked out the designs of promising devices, some of which proved very effective in military practice. An interesting activity of this branch of the Division, carried out in conjunction with the Science and Research Division of the Signal Corps, resulted in the production of small balloons, capable of maintaining themselves automatically at any desired altitude, by alternately throwing out liquid ballast and releasing gas. Balloons only nine inches in diameter (before inflating) adjusted to float at the altitude of a known prevailing air current, traveled easterly from Fort Omaha for a distance of nearly 1000 miles. It is now proposed to use such balloons to ascertain the air currents above the Atlantic between the American and European coasts.

In the field of Geology and Geography the opportunities for war activities were more numerous than one might suppose. (See Chapters 11 and 12.) The importance of utilizing geologists for service at the front was fully appreciated by the enemy, and a memorandum describing German methods, and indicating the usefulness of geological advice in military operations was presented to the Secretary of War in 1917 by the Division of Geology and Geography of the Research Council. A considerable development of such service took place in

our army before the Armistice. A handbook of Northern France and chapters dealing with the western front from a work on Topography and Strategy in the War, both by members of the Division, were gratuitously distributed in large numbers among officers of the army. At the request of the Military Committee on Education and Special Training the Division prepared text-books on Military Geology and Topography and on Introductory Meteorology for use by the Students' Army Training Corps. An exhaustive report on materials and facilities for road building, fortifications, and concrete ship construction was prepared by a committee of geologists and engineers representing every coastal state from Maine to Texas. The Division also supplied for the use of the Peace Commission much information on geological and geographical subjects, and coöperated in an advisory capacity with the Division of Military Intelligence and various other bureaus and commissions of the Government.

The rôle of medicine, hygiene, and surgery in the war is described in Chapters 16, 17, 18 and 19. In connection with this far-reaching work the Division of Medicine and Related Sciences was in a position to render a wide variety of services. The Surgeons General of the Army and Navy appreciated from the outset the possibilities of an organization whose function it was to bring into coöperation with their offices the many resources of laboratories and educational institutions throughout the country. A constant effort was made to recognize those applied sciences upon which medical problems are dependent and to include their representatives in the organization of the Division. In fact, no pains were spared to render the work as useful as possible, without limitation of scope. For example, when a shortage of the white mice used for pneumonia diagnosis was discovered, the Division immediately arranged with several coöperating laboratories to breed the large numbers needed. It is interesting to record that at the same period another Division of the Research Council was equally active in devising means for the extermination of the mice and other

rodents that were preying on the grain supply of the country.

The chief purpose of the Division of Medicine and Related Sciences was to mobilize the civilian, medical and related workers and laboratories in the United States, and thus to create a united medical service to assist in the solution of problems connected with the war. Urgent questions were brought to the attention of the Division by representatives of the War, Navy and Labor Departments, and the best available workers were then called upon to attack them. Scores of committees were formed for coöperative work, and in many instances individuals working independently devoted their entire time and laboratory facilities to war service. In this chapter it will suffice to indicate merely the general nature of some of the work undertaken.

"Shock," so diversified in its manifestation and so injurious in its effects, was the subject of extensive investigation by members of the Division, both at home and at the front. Under the auspices of the home committee, twenty-nine studies were carried on at ten stations, and while much remains to be explained, new light has been thrown on certain clinical aspects of the problem. Another important activity of the Division was the work of the Committee on Industrial Poisonings, directed during the war period to the study of the toxic effects of substances used in the manufacture of explosives and the detection of early signs of intoxication among munition workers. Fatigue in industrial pursuits, of special significance under the high pressure of military demands, but hardly less important under peace conditions, was also extensively studied, from the standpoint of hygienic conditions in industrial establishments, efficiency at different hours of the working day, and the physiological effects of fatigue. New methods of producing acetone, a necessary solvent for airplane varnishes, almost unobtainable during the early period of the war; the cultivation and collection of native medicinal plants, providing for example, all the digitalis needed by the army; tests of new antiseptics and studies of their application; investigations of

anerobic bacteria of importance in war wounds; methods of controlling trench lice and their eggs, and the preparation of effective insecticides and methods of delousing; the development of a method for the prevention of neuromata in amputation stumps after operations; improved means of sterilizing drinking water for large bodies of troops; studies of streptococcus infection, the cause and possible prevention by vaccination of Spanish influenza, skin grafting, a test for oxygen-lack in the air of submarines, improved means of blood transfusion, the velvet bean and its utilization as a food, substitutes for cane-sugar, the minimum vitamin requirement — these represent the character, though by no means the full extent, of the activities of the Medical Division.

The extensive work of the Psychology Committee, described in Chapters 20 and 21, was one of the most novel applications of scientific method made during the war. Here, as in many other cases, the existing conditions called chiefly for service rather than for research. The rating of soldiers on the basis of mental alertness, actually applied to some 1,700,000 men, proved an effective means of promptly eliminating those unfit for service and utilizing the others for purposes calling for different degrees of intelligence. The aid of psychological tests in determining the qualifications for flying, the fitness of aviators, and the psychological effects of high altitudes, was also of great importance. The recent adoption by Columbia University of psychological tests for entering students and the widespread application of similar methods in industrial establishments, are significant illustrations of the effects of the war.

Anthropology might be supposed a science remote from war, but a previously unrecognized discrimination against the taller native-born American was prevented when, on recommendation of the anthropologists, the minimum stature of 63 inches for acceptance in general military service was reduced to 60 inches. The statistical methods employed in the measurement of soldiers were also revised, and the resulting records have been classified and studied with reference to the origin of in-

dividuals in 157 sections of the United States, the subdivision being based primarily upon the racial constitution of the population.

In the broad field of agriculture, botany, forestry, zoölogy, and fisheries, numerous investigators and research agencies, brought into coöperation by this Research Council Division, organized much work of importance. Some of this was of an emergency nature, but in most cases the studies undertaken are no less applicable to the needs of peace than to those of war. The indication of sources of material for making the special charcoal required for gas-masks, and the presentation of evidence that certain native woods are better suited than African mahogany for airplane propellers, thus saving thousands of tons of shipping, are typical war activities, though both are not without application under post-war conditions. The extermination of rodent pests, undertaken in coöperation with the United States Biological Survey, was of special importance during the period of the war. The presence or absence in poultry food of certain substances influencing egg production was the subject of an extensive investigation, in which poultrymen both East and West took part. A group of soil and fertilizer specialists from North and South Dakota, Minnesota, Wisconsin, Iowa, Nebraska, Kansas, and Missouri was organized for the study of fertilizer problems of that large agricultural region, and the special coöperation of the Department of Agriculture was secured for a further investigation of the questions involved. The protein element in animal feeding and the physiological salt requirements of representative cultivated plants were the subjects of two other coöperative researches, involving the joint efforts of many investigators and laboratories. Other researches, too numerous to be mentioned here, also stand to the credit of the Division.

An outstanding fact in this work of the National Research Council is the splendid spirit of coöperation shown by those who took part in it. Personal rivalries were thrown aside, ideas and information were freely exchanged, and the one con-

cern of each investigator was to aid in the solution of the problem at hand. In many cases, if not in all, this spirit has survived the Armistice. It is safe to say that the direct losses suffered by science through the war, in men, in revenue, and in diversion of effort, will be largely compensated in the future if the advantages attainable through coöperation can be realized.

THE RÔLE OF
PHYSICAL SCIENCE
IN THE WAR

III

CONTRIBUTIONS OF PHYSICAL SCIENCE

ROBERT A. MILLIKAN

FROM the days of Alexander and Cæsar, if not from periods even more remote, the engineer has been a vital adjunct of a successful army; for war machines have always had to be built and operated, bridges thrown across rivers, roads rendered passable, new terrain surveyed and new fortifications designed and constructed. These and their like have been from the earliest times the standardized operations of the Engineer Corps of every army. But there is another and a quite distinct rôle which the physical sciences played in the great war. For never in the history of warfare up to the year 1914 had the whole scientific brains of any nation been systematically mobilized for the express purpose of finding immediately new ways of applying the accumulated scientific knowledge of the world to the ends of war.

It is not my purpose in this chapter to deal with the standardized operations of the technical corps of the army and navy during the great war. For this I have no competence. I shall endeavor rather to pass in rapid review the most significant of the newer developments which were due in large measure to the organized activities of scientists who, until the great war, had no association with things military. Many of these scientists, like the writer, became connected during the war either as officers or as civilian employees with the military departments of the Government. But whatever our official connection with the military service, we were all associated in our scientific activities through the National Research Council,

which acted in the United States as the great clearing house of scientific information, and as a coördinating and stimulating agency for scientific research and development work in aid of the war.

So far as developments in the physical sciences are concerned this coördinating and stimulating work was done through three main agencies, namely, first, the executive committee of the Division of Physical Sciences of the Research Council, second, the Research Information Service, and third, the weekly conference of the Physics and Engineering Divisions of the Council.

The National Research Council, being itself a voluntary association for research purposes of the scientific agencies of the country, civilian and governmental, industrial and academic, it was to be expected that the Executive Committee of its Division of Physical Sciences would embrace representatives of important scientific and technical agencies. Its membership was as follows: Prof. J. S. Ames, representing the National Advisory Committee for Aeronautics, Dr. L. A. Bauer of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, Dr. A. L. Day of the Geophysical Laboratory, Major A. L. Leuschner of the Chemical Warfare Service, Dr. C. F. Marvin, Chief of the Weather Bureau, Lt. Col. R. A. Millikan, representing the Signal Corps and the Anti-submarine Board of the Navy, Major F. R. Moulton of the Bureau of Ordnance of the Army, Major C. E. Menedenhall of the Bureau of Aircraft Production, Dr. E. F. Nichols of the Bureau of Ordnance of the Navy, Dr. H. N. Russell, associated with both the Engineer Corps and the Bureau of Aircraft Production, Dr. W. C. Sabine of the Advisory Committee for Aeronautics and the Bureau of Aircraft Production, Dr. Frank Schlesinger of the Bureau of Aircraft Production, General George O. Squier, Chief of the Signal Corps, Dr. S. W. Stratton, Head of the Bureau of Standards and Dr. R. S. Woodward, Head of the Carnegie Institution of Washington.

This committee held stated meetings for the formulation of

policies, the initiation of new projects, and for the detailed discussion of the seventy odd major research undertakings which had been initiated in large part at least by the Division and which its members were either directing or closely following. The opportunity both to initiate problems and to follow those initiated elsewhere, particularly abroad, came about chiefly through the most successful functioning of the second agency mentioned above, the Research Information Service.

This service had its inception in the Spring of 1917 when certain British scientists in the British ministry of munitions addressed a letter to General Geo. O. Squier suggesting the development of a liaison between British and American scientists. This letter was referred by General Squier to the Chairman of the Division of Physical Sciences of the National Research Council who laid the matter before the Military Committee of the Council, which committee embraced the heads of the technical bureaus of the navy and army, namely, Admirals Benson, Griffin, Taylor and Earle, and Generals Squier, Black, Crozier and Gorgas, in addition to the heads of civilian technical bureaus like Doctors Marvin and Stratton of the Bureau of Mines and the Bureau of Standards. This body discussed the proposal at some length and concluded that an even more comprehensive plan for bringing about coöperation and preventing duplication was needed. It accordingly appointed a committee consisting of Dr. Walcott, Mr. Howard Coffin, Dr. Stratton and Mr. Millikan to formulate recommendations. The committee formulated a plan which was approved by the Military Committee and then by the Secretaries of War and of the Navy and finally by the President, who appropriated \$150,000 from his war emergency fund for carrying the plan into effect.

This plan provided for the establishment of four new offices, one in Washington, one in London, one in Paris and one in Rome. The office in Washington was headed by a group of three men: the chief of the Army Intelligence Service, the chief of the Navy Intelligence Service, and the chairman of the National Research Council; the group in London, by the naval

attaché, (Admiral Sims himself) chosen by the National Research Council. The function of the scientific attaché in England, who was Dr. H. A. Bumstead, was to keep in touch with all research activity in that country and to send back almost daily reports to our office in Washington. Similarly, all reports of work done on this side were sent by uncensored mail or by cable to the offices of the scientific attachés in London, Paris and Rome, and distributed from there to the research groups in Europe. The navy coöperated heartily with this plan from the start, and Admiral Sims aided it in every possible way. As for the army, at the request of the General Staff, the Secretary of War issued orders to all army officers who were sent on scientific and technical missions to make duplicate reports, one to the officer who sent them and the other to the office of the scientific attaché, so that there might be a central agency through which an interconnection might be had between all kinds of new developments. The actual functioning of the Research Information Service had most to do with developments in the Physical Sciences.

Furthermore, through the authority conferred by the Military Committee, there was held in Washington at the offices of the National Research Council a weekly conference of the Division of Physical Sciences and of Engineering, which reviewed all the reports from abroad each week and put the workers on this side into the closest touch with the developments on the other side. The whole plan was an admirable illustration of the possibilities of international coöperation in research. In the submarine field, for example, all anti-submarine work in England, France and Italy which was reported by cable and by uncensored mail immediately to the office of the Research Council in Washington, was taken each Saturday night to New London and presented in digested form to the group of scientists which was working there continuously on submarine problems. Similar arrangements were made with the airplane research groups, sound-ranging groups, etc., so

that in the Research Information Service we had the first demonstration in history of the possibilities of international coöperation in research on a huge scale, a sort of coöperation which made it possible for any development, or any idea which originated in any of the chief civilized countries of the world to go at once, very frequently by cable, to all the other countries and to be applied there as soon as possible, or to stimulate carefully selected groups of competent technical men in these countries to further developments. The extraordinary rapidity with which scientific developments were made in the war was unquestionably due first, to the forming of a considerable number of highly competent research groups, and second, to the establishment of effective channels for the coöperation between these groups.

So much for the machinery by which the work in the Physical Sciences was stimulated and coördinated. As for the problems themselves it is only possible to sketch briefly the history of a few of the most important. Of them all the submarine problem stood out from the beginning of the war as of paramount importance. Effective attack upon it in this country started with the visit of the scientific mission which was sent to the United States in May, 1917, with definite official instructions from the French, British and Italian governments to hold back nothing, but to lay all the facts and plans of the Allies relating to scientific developments in aid of the war before properly accredited scientific men in the United States. The National Research Council, which acted as the host of this mission in the United States (for the mission had been sent here in return for a similar mission organized and sent abroad by the National Research Council in March, 1917) with authority conferred upon it by the War and Navy Departments, called a conference in Washington of some of the best scientific brains in the United States and for a period of a full week this conference met and discussed in detail the progress thus far made and the plans projected in the fields of submarine detec-

tion, of location of guns, airplanes and mines by sound, of ordnance, of signaling and of aviation instruments and accessories.

As a result of these conferences there were organized through the coöperative effort of the National Research Council and several of the bureaus of the army and navy, a considerable number of groups of scientific men, each of which was charged with the development of some particular field. For example, Professor Trowbridge, of Princeton, and Professor Lyman, of Harvard, were selected and placed in charge of the development in this country of the sound-ranging service. They and the group of scientific men whom they associated with them were first given commissions in the Signal Corps, and with Signal Corps authority and funds started development work in sound-ranging at Princeton University and at the Bureau of Standards. This whole group was later transferred to the authority of the Engineer Corps, but its directing personnel remained in the main unchanged and it did extraordinary work in the whole of the fighting of the summer of 1918, locating hundreds of guns by computing the center of the sound wave from observations made on the times of arrival of the wave at from three to seven suitably placed stations. This method had never been used in any preceding war and it proved extraordinarily accurate, a gun being located five miles away with an error of less than fifty feet.

Again it is not an over-statement to say that the most effective part of the anti-submarine work done in the United States grew directly out of that conference, and it grew out of it in this way. As Lord Northcliffe continually reiterated on his trip to the United States in the spring of 1917, the submarine problem was at that time *the* problem of the war, for while Europe might fight with little to eat, it could not fight without iron and oil and other supplies which this country alone could furnish, and in the spring of 1917 civilization trembled in the balance, because the submarine was seriously threatening to destroy all possibilities of transportation from

this country to Europe. The English scientists therefore, in particular, came to this country directed by their government to lay before the American scientists every element of the foreign anti-submarine program, whether already accomplished or merely projected, and in the conference under consideration a large part of the discussion centered around the submarine problem, which, as Sir Ernest Rutherford repeatedly pointed out, was a problem of physics pure and simple. It was not even a problem of engineering at that time, although every physical problem, in general, sooner or later becomes one for the engineer, when the physicist has gone far enough along with his work. Hence, since the number of physicists was quite limited, the number of men who had any large capacity for handling the problem of anti-submarine experimentation was small. These men were found mostly in university laboratories or in a very few industrial laboratories which employed physicists, and we unquestionably had gathered a very representative group of them together in the fifty men assembled in the conference at Washington. The success or failure of our anti-submarine campaign, and with it the success or failure of the war, so far as we were concerned, seemed to depend upon selecting and putting upon this job a few men of suitable training and capacity.

At the close of that conference a small committee was appointed to select ten men to give up their work and to go to New London to work there night and day in the development of anti-submarine devices. The men chosen were Merritt of Cornell, Mason of Wisconsin, H. A. Wilson of Rice Institute, Pierce and Bridgman of Harvard, Bumstead, Nichols and Zeleny of Yale, and Michelson of Chicago, although Professor Michelson was almost immediately taken off for other work of much urgency and Chicago was represented in a fashion by the writer who was there a portion of each week. This group worked under the authorization of the Secretary of the Navy and with the heartiest of coöperation from the Navy Department, although it was at first financed by private funds ob-

tained by the National Research Council. In the course of a few months, however, when it had demonstrated its effectiveness it was taken over by the Navy, which spent more than one million dollars on the experimental work at that place. This station with its chief scientific personnel not largely changed became the center of our anti-submarine activity, and with other stations, one at Nahant, Mass., embracing chiefly the physicists of the General Electric Company, the Western Electric Company and the Submarine Signaling Company, one in New York presided over by Dr. Pupin, of Columbia, and one in San Pedro, Calif., which, like the New York station, was organized under the Research Council, made remarkable progress in the rapid development of anti-submarine devices — devices which exerted a notable influence upon the reduction of submarine depredations, and made it possible even by the fall of 1917, to predict that the submarine menace could be eliminated.

Unquestionably the most effective device developed in America, and one which played a real rôle in the elimination of that menace, was one which had the following origin. The French had already developed an apparatus consisting of a sort of great sound lens which brought the incoming pulses together in the same phase at the center of the lens near the bottom of the hull. This was presented and discussed at length in the conference. A full official report of the device was sent by the French government to the Anti-submarine Board of the Navy, and at a meeting of that board the writer requested to be allowed to take this report to the group of scientists at New London for the sake of a thorough analysis of it, for he felt confident, and so stated at the time, that through such an analysis we would obtain variants of the device which would be an improvement upon it. This procedure was followed and for two days ten men assembled at a hotel in New London and studied that report, drawing up four or five different variants of this device to develop and try out. The most successful and effective detector which actually got into use in the war was one of these variants of the original French device

suggested and largely developed by Mason. It consisted of a row of from thirty to sixty sound receivers strung along in two rows one on either side of the keel of the ship, well forward; the sound pulses coming in to all of the receivers on one side were arranged to travel in tubes of just such length as to cause them all to unite in the same phase at the mouth of a tube leading to one ear of the observer, while all the sound pulses received by the other row are brought together in a similar way at the other ear. By now using the binaural sense to equate exactly the sound paths to the two ears, it is possible to locate the direction of the source of sound to within one or two degrees. This instrument could pick up submarines from one to ten miles away depending upon their speed and the weather conditions. A variant of the multiple receiver device, using microphones and electrical compensators to equate phases in place of ordinary sound receivers and sound compensators, was even more effective. Many of our submarines and destroyers which went across during the summer of 1918 were equipped with the acoustical form of this device, and now the electrical form is being still further developed for peace use, rather than for war, for it is possible through it to eliminate the chief terror of the sea, namely, collision in fog. And, when it is remembered that the preventing of a single disaster like the sinking of the *Titantic* or of the *Empress of Ireland* more than pays, without any reference to the value of human lives, for all the time and money spent by England, France and the United States combined in developing detecting devices, it will be seen how shortsighted a thing it is for any country to fail to find in some way the funds necessary for carrying on research and development work in underwater detection. For decades and for centuries we have allowed ships to go down year by year needlessly, simply because we have not realized the possibilities of prevention through properly organized scientific research in this field.

Another device capable of detecting a lurking submarine half a mile or more away by the use of a beam of sound waves of

very high frequency was perfected too late to be of use, but it represents a war development of extraordinary interest. The credit for it is due primarily to Dr. Langevin of Paris, though the New York and San Pedro groups of American physicists did excellent work in the same direction following Langevin's lead. Other anti-submarine devices in considerable number were developed and effectively used, but these two are in most respects the most notable.

But it has not merely been in sound-ranging and in submarine detection that the war has demonstrated the capabilities of science. Every single phase of our war activities has told the same story. Turn, for example, to the development of new scientific devices for use with aircraft. How was that handled? The Science and Research Division of the Signal Corps, organized through the coöperation of the Signal Corps and the National Research Council, and later transferred to the Bureau of Aircraft Production, had a group of as many as fifty highly trained men, physicists and engineers, who were working in Washington and in the experimental station at Langley Field, twelve hours a day, seven days a week, on aviation problems—one group on improvements in accurate bomb dropping, another on improvements in airplane photography, another on the mapping of the highways of the upper air in aid of aviation, another upon balloon problems, such as the development of non-inflammable balloons, another on aviation instruments, compasses, speed meters, etc., and producing the best there are in the world, and finally a group on new sensitizing dyes for long wave-length photography, etc. Let me select for special comment the most important physical principles which have just now for the first time found large and effective application in war. I shall classify these under six heads.

The first two of these are (1) the principle of binaural audition and (2) the principle of sound-ranging (locating the position of a gun by plotting the sound wave emanating from it). These two share the honor of having proved themselves the

most useful and effective of the new applications of physics to the purposes of war. The second was responsible for the location and destruction of thousands of enemy guns, while the first was responsible for the location and destruction of submarines, airplanes and mines.

The binaural principle itself was unknown even to most physicists before the war, though it is used by all of us when we turn our heads until we think we are looking in the direction from which a sound comes. The accuracy with which this can be done in the absence of disturbing reflections is surprising. When the observer has set his head so that the sound pulses from the source strike the two ears at exactly the same time he has the sense that the source lies in the median plane between the two ears. If the sound pulses strike one ear first, the observer has the sense that the source is on the side of the ear which is struck first. This sense is not due in any appreciable degree to intensity differences produced by shadow effects of the head. It has to do practically entirely with phase differences. The principle is beautifully illustrated by inserting into each ear one end of a piece of rubber tubing four or five feet long and scratching or tapping on the wall of the tubing, first at a point slightly closer to one ear than the other and then moving the tapping object slowly through the mid-point to a position nearer the second ear. The sound of the scratching or tapping will then appear to the observer to be in the ear which is nearest to it and then to move around the head to the other ear as the mid-point is crossed. With the unaided ear one can locate direction in this way to within five or ten degrees. The simplest way to increase the *sensibility* of the method to faint sounds is to increase the size of the ears by providing them with trumpet-like extensions. To increase the *accuracy* of location one stretches out the receiving ends until the distance between them is say, five or six feet instead of five or six inches, as it is in the case of the unaided ear. It is then only necessary to turn the whole receiving system through about one-twelfth the former angle to obtain the same

phase difference. The angular accuracy of setting is thus increased twelve fold.

Two methods of applying the principle were used in the war. The one consisted in rotating the whole receiving system, one side of which was connected with a rubber tube to one ear, the other side in the same way to the other ear, until the observer had the sensation of feeling the sound pass from one ear to the other. At this instant he knew that the source was directly ahead of the line connecting the two receivers, or else directly behind this line, the distinction between the two positions being obtainable from the relation between the direction of the motion of the head and the direction in which the sound seemed to pass from one ear to the other. The second method, the one used with the submarine detector discussed above, consisted in keeping the receiving system fixed in space and changing the length of the sound path from each receiver to the ear by means of a so-called rotating commutator until the sound seemed to be passing from one ear to the other. The reading of the dial on the compensator then gave the direction of the source.

This principle proved so effective in locating enemy mining and tunneling operations that according to official despatches received by the Research Information Service both sides gave up such operations practically entirely a year or more before the close of the war. It was equally effective in anti-submarine warfare, a very simple form of binaural detector having been put out in large numbers by the General Electric Company, in addition to the more elaborate and more effective devices heretofore considered. The principle was less effective in its application to anti-aircraft work though even here it served a very useful purpose.

The third physical principle which was of immense use in the war was the principle of amplification. This extraordinary application of scientific investigations of the past two decades in the field of electron discharges had been reduced to practice in the telephone industry in 1914 when transcontinental wire

telephony became for the first time possible through the development of the De Forest audion into a telephone repeater and amplifier — an advance which not only extended enormously the possibilities of communication, but saved at once millions of dollars even in the construction of short telephone lines. With six stage amplifiers of this electronic sort the energy of speech has been multiplied without distortion as much as ten thousand billion fold. Small wonder then that by 1915 enormously amplified wave forms produced by speech had been impressed on the ether from the Arlington Towers with such energy as to be picked up and distinctly understood in Paris and Honolulu. But in spite of the success already attained in this field by the physicists of the telephone company, when the United States entered the war the principle of amplification had not been successfully applied either to inter-communication by wireless phone between ships (for example, submarine chasers) or between airplanes, and one of the most pressing problems which General Squier put up in April, 1917, to the Division of Physical Sciences of the Research Council was the problem of wireless communication between planes. This was solved by the mid-summer of 1917 by the group of physicists of the Western Electric Company to whom it was referred and, on Sunday following Thanksgiving 1917, for the first time in history, airplanes in flight were directed in official tests at the Wright field in Dayton, Ohio, in intricate maneuvers, from the ground or by the commander in the leading airplane, and reports and directions were given and received in clear speech. For wire and wireless telephone receiving, sending and amplifying on sea and land three-quarters of a million vacuum tubes were built by the Western Electric Company alone for the purposes of the war, and half as many more by the General Electric Company, so that the amplifying principle was of scarcely less importance in the successful conclusion of the war than were the principles of binaural location and sound-ranging.

The fourth tremendously important and altogether new ap-

plication of the principles of physics to warfare was made in the field of airplane photography. In this field as in those of submarine detection and sound-ranging, though not in that of amplification, we followed the developments of the British and the French, though contributing important elements ourselves. The war could scarcely have been fought at all without the airplane photographer who was the very eyes of the army. American developments in this field were organized by the Science and Research Division of the Signal Corps which in the summer of 1917 assembled a group of physicists and photographic experts under the direction of Dr. H. E. Ives. This group in closest coöperation with the Eastman Kodak Company of Rochester and the Burke and James Company of Chicago developed what are probably the finest airplane cameras in existence. In addition it developed color filters for detecting camouflage and increasing visibility of such value that forty thousand of them were used in the army and navy. It produced new dyes for use in the production of pan-chromatic plates designed to be used for the penetration of haze in airplane photography and made other advances in this important art which bid fair to revolutionize the whole process of surveying, since an airplane photograph taken in a few seconds can give information which it used to take months to acquire by laborious triangulation methods.

The fifth great new application of physics to warfare lay in the developments in meteorology and in the principles of ballooning. The realization of the possibility of non-inflammable helium balloons and the actual production of small propaganda balloons which dropped their loads a thousand miles from the starting point are among the most spectacular and interesting scientific developments of the war, but neither of them played any actual part in achieving the victory. Of untold importance, however, was the careful though unspectacular work of the meteorological section of the Science and Research Division of the Signal Corps which by thousands of pilot balloon flights accumulated the data that not only aided

the flyer in his work at the front, but made possible the so-called ballistic wind corrections upon which the effectiveness of both the artillery and the sound-ranging services largely depended. When it is remembered that the biggest element in the effectiveness of a modern army is its artillery and that the effectiveness of the artillery is dependent entirely upon these wind corrections it will be seen how incalculably valuable the work of the trained physicists and mathematicians proved to be to the practical problems of the great war.

The sixth and last of the new applications of physics to the purposes of the war has to do with the principle of signaling by visible light rays, by infra-red rays, by ultra-violet rays and by super-sound rays. In all of these fields there were developments of great interest and of much importance for the future, though none of them contributed largely to the victory of the Allies. In bombardments all the wire and wireless methods of communication often failed and light signals of some sort were the only reliance. Special signaling lamps were developed by the Science and Research Division of the Signal Corps and ordered in considerable numbers. A notable system of secret signaling with infra-red rays was developed by Theodore Case of Auburn, N. Y., and successfully used in keeping convoys together at night when lights could not be used. The possibility of having secret ultra-violet methods of guiding aviators at night back to their landing fields was demonstrated by R. W. Wood. As already indicated super-sound signaling under water was successfully accomplished by Dr. Langevin and applied experimentally in submarine detection.

Outside the lines of the foregoing classification there were some developments in Physics which deserve mention. Thus a leak proof gasoline tank for airplanes, developed by Dr. Gordon S. Fulcher in collaboration with the Miller Rubber Company of Akron, Ohio, which could be shot through by scores of bullets without leaking a drop of gasoline or catching fire even when the bullets were incendiary, had at the close of the war been ordered placed on all American combat planes.

It promised to do away with the chief terror of the American flyer, namely, coming down in flames. An airplane compass and a speedmeter developed by Major Mendenhall and Lieut. Williamson, in coöperation with the General Electric Company were used on all American planes. Dr. Duff, Captain Webster, Captain Sieg and Captain Brown increased notably the accuracy in bombing, a matter of the greatest importance since doubling the accuracy in dropping bombs is more than equivalent to doubling the production of bombing planes. Under the stimulus of the war Dr. Coolidge developed a new and improved x-ray tube for use in field hospitals. Dr. E. F. Nichols developed a new type of mine, which was used in mining operations in the North Sea. Prof. A. A. Michelson developed a new and improved range finder, which was accepted by the Navy Department. Prof. Raymond Dodge developed a new piece of physical apparatus for the selection and training of gunners. This instrument was adopted and used both by the American and foreign navies. Optical glass was produced in large quantities for the first time in the United States under the guidance of a committee of the Physical Science Division of the Research Council, consisting of Drs. A. L. Day, S. W. Stratton and R. A. Millikan.

This is but an incomplete sketch of what look now like the most important developments in Physics which were stimulated by the war. Scores of other problems were undertaken the results of which may in the end be as useful both for the purposes of war and for those of peace as any of those herein set forth.

IV

SOME SCIENTIFIC ASPECTS OF THE METEOROLOGICAL WORK OF THE UNITED STATES ARMY¹

ROBERT A. MILLIKAN

THERE is no more interesting illustration of the application of new scientific methods to warfare than is furnished by the developments in meteorology during the great war. Prior to 1914 a meteorological section was not considered a necessary part of the military service. No corrections had ever been made by the artillery of any army for any save surface winds. Firing by the map was almost unknown. No Sound-ranging Service, no Air Service and no Anti-aircraft artillery had ever existed to demand aërological data.

At the time of the signing of the armistice on the western front the Air Service and all the artillery were being furnished every two hours with the temperature, density, wind-speed and direction, taken at the surface and at various altitudes, from 100 to 500 meters apart, up to 5,000 meters. Further, tables were prepared from which each battery could obtain the correction suited to its trajectory for the so-called ballistic wind. This is the average wind for the trajectory, weighted for the density of the air at the elevations traversed. Even machine guns when used for barrage work made use of these ballistic-wind tables.

In addition, daily forecasts were furnished to the armies in accordance with the following outline:

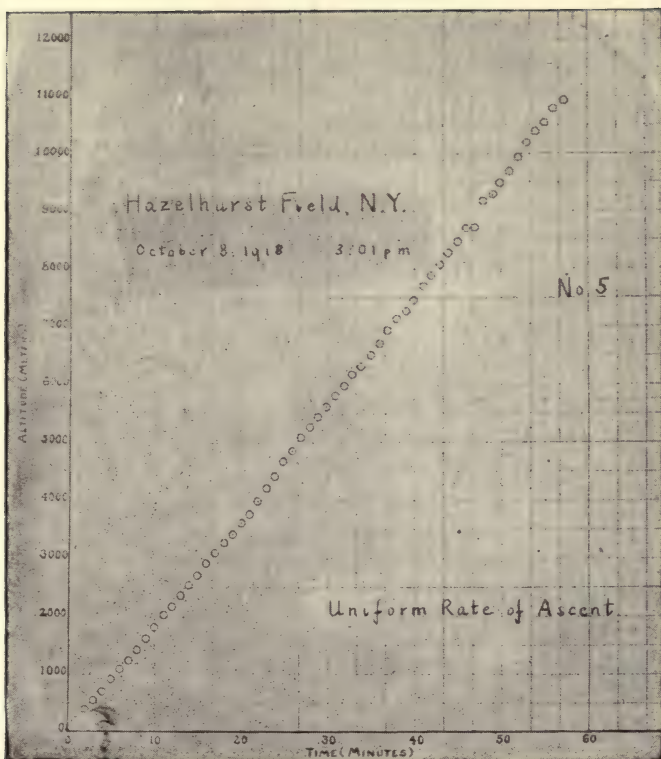
¹ Reprinted by permission, with the omission of certain illustrations, from the Proceedings American Philosophical Society, vol. 58, 1919.

- A.* Character of weather for each arm of the service.
- B.* Winds: Surface, at 2,000 m., at 5,000 m.
- C.* Cloudiness including fog and haze.
- D.* Height of cloud.
- E.* Visibility.
- F.* Rain and snow.
- G.* Temperature.
- H.* Warning of weather conditions favorable for use of gas by enemy.
- K.* Probable accuracy or odds in favor of forecast.

Most of the aërological data were obtained from theodolite observations on pilot balloons. The extent to which our knowledge of the upper air has been, and is being, extended by this pilot balloon work may be seen from the fact that before the war there existed but one station in the United States where pilot balloon explorations were regularly carried on. Within a year of the inception of the meteorological service in the United States Army, thirty-seven complete stations for the obtaining of both surface and upper air data in aid of aviation and the artillery had been established in the United States and equipped with special aircraft theodolites and pilot balloons, neither of which had ever been produced before in this country. Further, twenty such stations had been established by our forces abroad. For the manning of this service, about five hundred specially selected men had been trained in this country, and three hundred and fourteen of them sent abroad, while about two hundred were held for work in the United States.

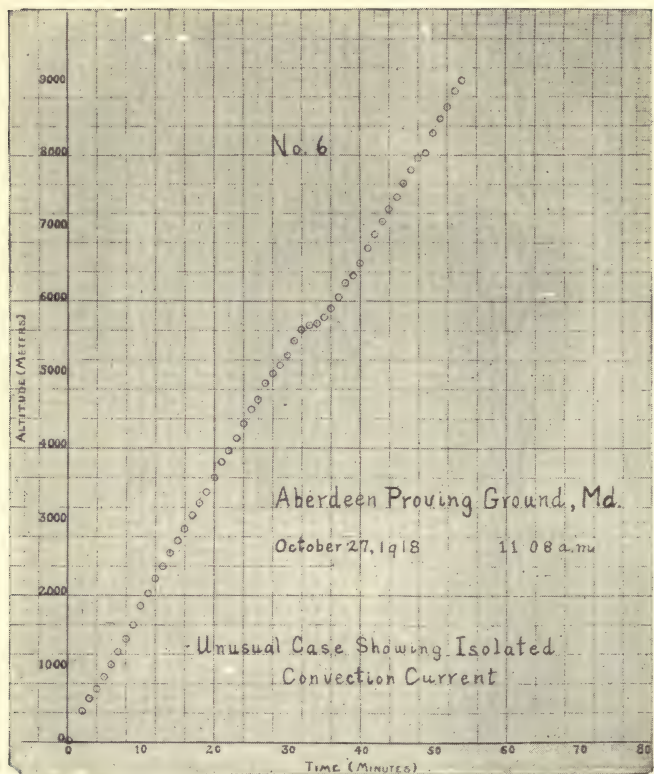
The scientific interest in this service centers about four distinct problems:

1. The extension of our knowledge of the law of motion of pilot balloons.
2. The procurement of data and the development of methods for the preparation of artillery range table.



Courtesy of American Philosophical Society

Figure 1. Uniform rate of ascent of pilot balloon up to 11,000 meters



Courtesy of American Philosophical Society

Figure 2. Pilot Balloon ascent showing isolated convection current

3. The development of long range propaganda balloons.
4. The charting of the upper air in the United States and overseas in aid of aviation.

1. *The Extension of Our Knowledge of the Law of Motion of Pilot Balloons.*—Prior to the development of the meteorological service of the army there had been made in the United States perhaps one hundred pilot balloon flights in which the balloons had been followed by the two-theodolite method—the only method which permits of real accuracy—and in several European countries there had been a somewhat greater number, but the data were incomplete and fragmentary.

Within the past year approximately five thousand such observations have been taken by the meteorological service of the Signal Corps. From these observations the altitude of the balloon is determined with great accuracy by triangulation, the base line being usually a mile or more in length. The balloon is kept in sight up to distances as great as sixty miles, and up to heights as great as 32,000 meters, or approximately twenty miles. For the practical uses of the artillery and the air service, observations need not be carried higher than 10,000 meters (six miles), which is the extreme height to which airplanes have thus far ascended, or to which projectiles usually go.

In view of the number of variables which enter into the rate of ascent of pilot balloons, such as the changing density and the changing temperature of the surrounding air, the changing size of the balloon and consequent changing tension of the rubber envelope, the changing temperature of its interior because of the absorption of the sun's rays, the diffusion of hydrogen through its walls, etc., it is one of the most striking facts to be found anywhere in the annals of empirical science that these balloons rise to great heights without deviating appreciably from the simplest possible law of ascent, namely that of constant speed. Graph No. 5¹ shows a beautiful example of this con-

¹ Graphs 1, 2, 3, and 4 are omitted from this volume.

stancy. Graph No. 6 shows a kink at about 5,500 meters, which is presumably due to a descending current struck at that altitude. Graph No. 7 is that of a balloon followed to a height of 20,000 meters where it apparently developed a leak and failed to ascend further. Graph No. 8 shows the fluctuations which are often found at low altitudes, these fluctuations being undoubtedly due to ascending and descending currents.

The extreme constancy in the rate of ascent, shown in a great majority of flights, although surprising enough is not as inexplicable as it at first appears, for since the pressure within the balloon due to the tension of the rubber itself is only from five to eight centimeters of water, and since this pressure is at sea level less than 1 per cent. of the pressure of the atmosphere, it will be seen that the balloon will expand practically freely, that is, as though the walls did not constrain it at all, up to heights of say 10,000 meters where the pressure is about a third of an atmosphere. This means that the ascensional force must be entirely independent of temperature and pressure.¹ For the speeds with which these balloons ascend, namely, about three meters a second, the resistance to motion must be directly proportional to the density of the air and experiment shows it to be nearly proportional to the cross section of the balloon, that is, to the square of the radius. This makes the resistance vary as the cube root of the density,² which means that at a height of 6,000 meters, where the density is about one-half, the resistance is .83, of what it would be at the surface.

¹ For if f_1 , d_1 , $v_1 p_1 t_1$ represent ascensional force, density, volume, pressure and temperature at the surface of the earth, and f_2 , d_2 , v_2 , p_2 , t_2 , the corresponding quantities at any given elevation, then since $d_2/d_1 = p_2 t_1 / p_1 t_2$ (1) and $f_1/f_2 = v_1 d_1 / v_2 d_2$ (2) there results from a combination of 1 and 2 $f_1/f_2 = v_2 d_1 / v_2 d_2 = p_2 t_1 / p_1 t_2 \times p_1 t_2 / p_2 t_1 = 1$.

² For if R_1 is the resistance at the earth's surface and R_2 that at any given altitude,

$$\frac{R_1}{R_2} = \frac{V_1^{\frac{2}{3}} d_1}{V_2^{\frac{2}{3}} d_2}$$

which is seen from (1) to equal

$$\left(\frac{d_1}{d_2} \right)^{\frac{1}{3}}.$$

If, as is approximately true for these speeds, the resistance varies as the square of the velocity, or the velocity as the square root of the resistance, this would mean that the velocity should vary as the sixth root of the density. In other words, since the sixth root of 2 is 1.13, at a height of 6,000 meters, the velocity should be about 13 per cent. greater than at the surface. Such an increase in velocity would be very easily observable in the experimental data. The fact that it is not found there is due to the wholly fortuitous circumstance that the slow diffusion of hydrogen through the walls, as observation by Blair and Sherry has shown, is just sufficient, with the balloons here used, to retard the ascensional rate enough to make it quite exactly constant.

This makes it possible, provided one could always duplicate the size and weight of his balloon, to obtain a very exact determination of wind velocity and direction by a one-theodolite method, the height being always known from the time and the known rate of ascent.

When, however, the weight and inflation of the balloons are varied, as they must be in practice, since the balloons vary in weight from twenty to thirty-five grams, and since it is convenient also to vary the filling according as low altitude or high altitude wind-data are desired, it is found that no accurate formula can be found for computing the speed in terms of the ascensional force, the weight to be lifted, and a single invariable constant. For approximate work, however, the one-theodolite method, because of its convenience and because of the impracticability of measuring an accurate base line at the front, is much in use, and one of the advances made in the meteorological work of the army during the past year has consisted in developing with the aid of the large amount of data available, a general formula for the rate of ascent in terms of the ascensional force and the weight to be lifted, which though far from accurate is more reliable than that which has heretofore been used. The formula heretofore used is that of Dines, namely,

$$V = K \frac{l^{\frac{1}{2}}}{L^{\frac{1}{3}}},$$

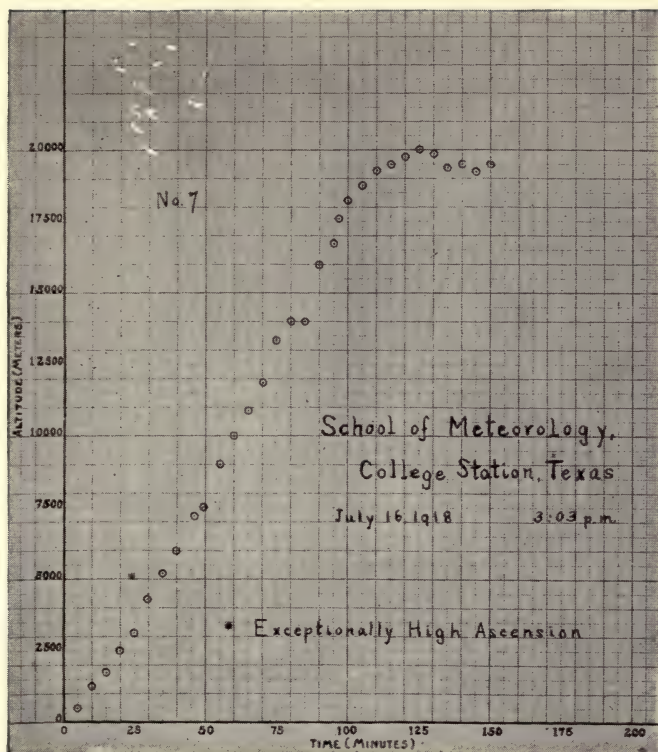
in which V represents the rate of ascent in meters per minute, l is the free lift, or the weight of the displaced air less the weight of the balloon and contained hydrogen, L is the weight of the balloon plus the free lift and K is a constant.

The formula as modified by the observers of the Signal Corps is

$$V = K' \left(\frac{l^3}{L^2} \right)^{.208}$$

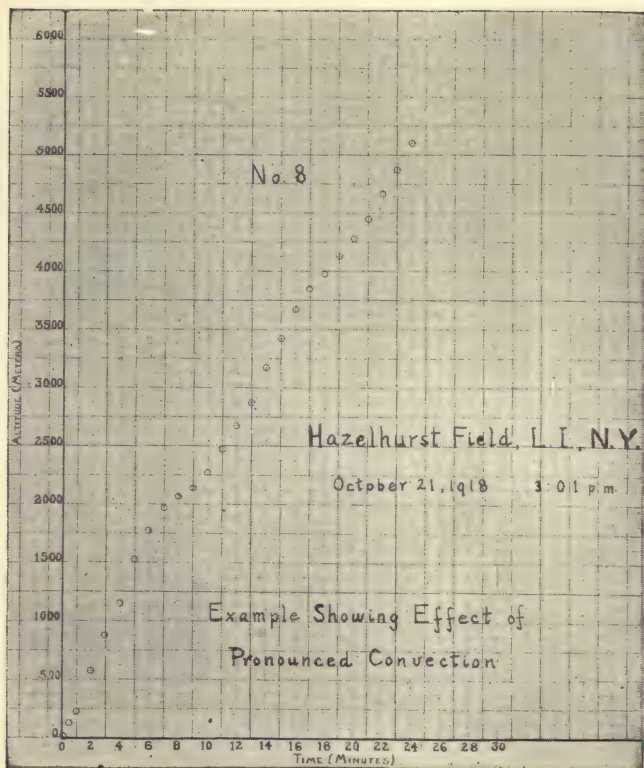
This formula is found to fit the observational data within the ranges used in the Signal Corps work to an accuracy of somewhat less than 10 per cent., which is sufficient for most work at the front.

2. *Meteorology in the Aid of the Artillery.*—In former times when guns did not shoot to a greater distance than eight or ten miles, it was usually possible to observe where the projectile hit and to correct by “spotting.” This made unnecessary the correction of the trajectory for the influence of the wind and the changing density of the air with increasing altitude. In the present war, however, guns have been built to shoot much farther and in addition camouflage has prevented the visual location of guns even at the old ranges. Hostile batteries have been located in many instances solely by the new art of sound-ranging which has itself demanded for the high accuracy attained aërological data. The answering battery has been obliged to fire wholly by the map, so that it is obvious that it has become necessary to make careful allowances both for the density of the air and the direction and speed of the wind at various altitudes. Some of the modern projectiles remain in the air as long as seventy seconds and a moderate wind blowing across the path of such a projectile might easily cause it to drop half a mile away from the point at which it would strike if fired in still air. The wind-direction and speed at various altitudes have been obtained, as already indicated by pilot bal-



Courtesy of American Philosophical Society

Figure 3. Uniform rate of ascent of pilot balloon up to 20,000 meters where balloon sprung a leak



Courtesy of American Philosophical Society

Figure 4. Convection currents at low altitudes

loons, while the temperature has been determined at the proving grounds by sending self-recording instruments aloft in specially constructed box-kites, as well as by sending self-recording instruments and meteorological observers aloft in airplanes. It has been with the aid of observations of this sort that the new range tables for the Ordnance Department of the United States Army have been constructed. The importance of this work may be understood when it is considered that these range tables will be used in connection with the firing of all guns, and errors in them would produce errors in the range of every gun fired with their aid.

3. *The Development of Long Range Propaganda Balloons.*
—In view of the fact that above an altitude of 10,000 feet 95 per cent. of the winds both over western Europe and over the United States blow from west to east (*i. e.*, have a westerly component), Captain Sherry in 1917 suggested the development of a large program for the extension of the use of pilot balloons for the purpose of flooding the whole of Germany and Austria with propaganda dropped from such balloons. The project was submitted to the meteorological and military agencies in France and pronounced infeasible, chiefly because the rapid diffusion of hydrogen through rubber had heretofore rendered it impossible to obtain pilot balloon flights of more than about 100 miles. Undiscouraged, however, by these reports, Mr. W. J. Lester, Dr. S. R. Williams and Sergeant Redman attacked the problem of extending the range of pilot balloon flights by developing an automatic ballast-control and by reducing the diffusion by means of a special dope.

The automatic control was ingeniously simple, its essential feature being a belly band which kept the girth of the balloon constant (at a diameter of four feet) through the discharge, in the act of shrinking, of a few drops of kerosene, thus causing reascension and consequent expansion.

With this device the balloon not only does not fall but rises very gradually to higher and higher levels until its ballast of kerosene or alcohol is exhausted.

In the week beginning October 3, 1918, sixty such balloons, adjusted to fly between the initial and final altitudes of 15,000 and 25,000 feet respectively were sent up from Fort Omaha, Nebraska, carrying return cards and watches, which were arranged to stop and be let down on small parachutes as soon as the ballast was exhausted. Thirty-four out of sixty of these balloons were picked up and returned to Washington. Instead of flying 100 miles, one of them came down within ten miles

TABLE 1

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.

Station Ellendale, N. D. (90th Meridian Time.)

Wind Aloft Report.

Time 7:00 A. M.

Date November 13, 1918.

Altitude, Meters.	Direction, Compass.	Veloc- ity, M. P. H.	Re- marks.	Altitude, Meters.	Direction, Compass.	Veloc- ity, M. P. H.	Re- marks.
0	SW	29		5,250	NW	57	
250	S	17		5,500	NW	60	
500	SW	16		5,750	NW	59	
750	SW	15		6,000	WNW	63	
1,000	W	15		6,250	NW	69	
1,250	W	16		6,500	NW	68	
1,500	WNW	18		6,750	NW	68	
1,750	WNW	19		7,000	NW	74	
2,000	WNW	22		7,250	NW	77	
2,250	WNW	25		7,500	NW	85	
2,500	WNW	27		7,750	NW	65	
2,750	WNW	34		8,000	NW	73	
3,000	WNW	35		8,250	NW	76	
3,250	NW	35		8,500	NW	69	
3,500	NW	40		8,750	NW	75	
3,750	NW	41		9,000	NW	73	
4,000	NW	41		9,250	WNW	74	
4,250	NW	47		9,500	WNW	68	
4,500	NW	53		9,750	WNW	65	
4,750	NW	56		10,000	WNW	78	
5,000	NW	54		10,250	NW	81	

TABLE 2

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL
SERVICE.

Station Groesbeck, Texas. (90th Meridian Time.)

Wind Aloft Report.

Time 7:00 A. M.

Date November 1, 1918.

Altitude, Meters,	Direction, Compass.	Veloc- ity, M. P. H.	Re- marks.	Altitude, Meters,	Direction, Compass.	Veloc- ity, M. P. H.	Re- marks.
0	E	9		6,750	WNW	25	
250	ESE	16		7,000	WNW	19	
500	ESE	13		7,250	W	8	
750	ESE	2		7,500	W	12	
1,000	WSW	5		7,750	W	9	
1,250	WNW	11		8,000	WSW	4	
1,500	WNW	18		8,250	WSW	16	
1,750	WNW	23		8,500	WNW	20	
2,000	NW	25		8,750	W	22	
2,250	NW	20		9,000	WSW	20	
2,500	WNW	20		9,250	WSW	20	
2,750	NW	23		9,500	WSW	22	
3,000	NNW	21		9,750	WSW	28	
3,250	N	18		10,000	W	39	
3,500	NNW	29		10,250	W	47	
3,750	NW	25		10,500	W	50	
4,000	NNW	20		10,750	WNW	59	
4,250	NW	20		11,000	WNW	57	
4,500	NW	21		11,250	W	44	
4,750	NW	20		11,500	W	39	
5,000	WNW	16		11,750	W	41	
5,250	WNW	18		12,000	W	47	
5,500	WNW	35		12,250	W	51	
5,750	WNW	35		12,500	W	56	
6,000	WNW	32		12,750	W	59	
6,250	WNW	25		13,000	W	60	
6,500	WNW	26		13,250	W	64	

of New York, 1,100 miles from Fort Omaha, another was re-
turned from Virginia, 930 miles from its starting point, and
the rest were scattered over Ohio, Kentucky, Illinois, Wiscon-

sin and Iowa. Not one went west of Omaha though the balloons were sent up on days on which different surface conditions prevailed.

The credit for this achievement, the significance of which will be discussed later, is due primarily to Mr. Lester, Captain Sherry, Dr. Williams and Sergeant Redman. At the time of the signing of the armistice the Military Intelligence Service was preparing for the extensive use of these balloons for flooding the whole of Germany, Austria and even parts of Russia with suitable leaflets, several hundred of which could have been scattered by a single balloon, the total cost of which would have been but two or three dollars.

4. *The Charting of the Upper Air in Aid of Aviation.*—In a recent Brisbane editorial the following sentence occurs: "Flying machines of the future going long distances will travel at least 32,000 feet up, where no wind blows except the gentle eastern wind caused by the earth's motion on its axis." It is quite likely that the future aviator will fly high, but his motive will be to find an air current, not to escape one. The

TABLE 3

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.

Station Ellendale, N. D. (90th Meridian Time.)

Wind Aloft Report.

Time 8:26 A. M.

Date December 5, 1918.

Altitude, Meters,	Direction, Compass.	Velocity, M. P. H.	Re- marks.	Altitude, Meters,	Direction, Compass.	Velocity, M. P. H.	Re- marks.
0	NW	19		1,750	NW	64	
250	NW	47		2,000	WNW	68	
500	NW	49		2,250	WNW	81	
750	NW	57		2,500	WNW	87	
1,000	NW	48		2,750	WNW	96	
1,250	WNW	49		3,000	WNW	93	
1,500	WNW	50					

TABLE 4

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.

Station Mineola, L. I. (75th Meridian Time.)

Wind Aloft Report.

Time 7:06 A. M.

Date September 7, 1918.

Altitude, Meters,	Direction, Compass.	Veloc- ity, M. P. H.	Re- marks.	Altitude, Meters,	Direction, Compass.	Veloc- ity, M. P. H.	Re- marks.
0	N	18		2,000	SW	25	
250	N	51		2,250	SW	37	
500	N	65		2,500	SW	63	
750	N	29		2,750	SW	55	
1,000	W	22		3,000	SW	54	
1,250	W	20		3,250	SW	55	
1,500	W	11		3,500	SW	81	
1,750	WSW	13					

gentleness of the zephyrs existing at high altitudes may be seen from tables 1, 2, 3, 4 and 5 which record three sets of pilot balloon observations recently taken by the Signal Corps. These tables show air currents increasing in intensity with increasing altitude and approaching the huge speed of 100 miles per hour. Such speeds are perhaps exceptional, but not at all unknown. The pilot balloon mentioned in 3 traveled from Omaha to Virginia at an *average* speed of thirty miles per hour, the average height being 18,000 feet. On November 6, 1918, at Chattanooga, Tennessee, a velocity of 154 miles an hour at an altitude of 28,000 feet was observed by one of the meteorological units of the Signal Corps.

These facts bring out the importance of a forecast of such currents for the purposes of long flights. A flier aided by such a wind as that last mentioned would move toward his objective 2×154 , or 308 miles an hour more rapidly than if he were opposed by it. When it is recalled that the aviator above the clouds has no means of knowing anything about the motion of

the air in which he flies, it will be seen that it is of the greatest importance to him to know the nature of the currents at different levels. Table 4 furnishes a very typical illustration of this importance. From the above data it is evident that an avi-

TABLE 5

WAR DEPARTMENT, SIGNAL CORPS, U. S. ARMY, METEOROLOGICAL SERVICE.

Station Fort Oglethorpe, Ga. (90th Meridian Time.)

Wind Aloft Report.

Time 7:39 A. M.

Date November 29, 1918.

Altitude, Meters,	Direction, Compass.	Veloc- ity, M. P. H.	Re- marks.	Altitude, Meters,	Direction, Compass.	Veloc- ity, M. P. H.	Re- marks.
0	NW	7		1,750	W	36	
250	NW	8		2,000	W	41	
500	NW	11		2,250	W	46	
750	WNW	19		2,500	WSW	47	
1,000	W	29		2,750	WSW	56	
1,250	W	34		3,000	WSW	76	
1,500	W	36		3,250	WSW	96	

TABLE 6

Altitude In Meters.	Wind Direc- tion.	Wind Velocity In Miles per Hour.
Surface.....	NW	2.2
500.....	E	5.8
1,000.....	E	8.3
2,000.....	NE	5.4
3,000.....	W	5.4
4,000.....	NW	24.6
12,000.....	NW	49.2

ator flying toward the west at this time and place should have flown at an altitude of 1,000 meters, while an aviator flying toward the east should have flown at an altitude of 4,000 meters or more.

In order to meet the obvious need of the aviator for a knowl-

edge of upper air currents the Signal Corps in the summer of 1917 undertook for the first time in history a general program of mapping the upper air currents of the United States, the Atlantic and western Europe in aid of aviation and particularly with reference to trans-Atlantic flight. By the fall of 1918 twenty-six upper air stations, carefully distributed over the United States, were in full operation in place of the one station which had existed before the war. From these stations reports are telegraphed twice daily to the Weather Bureau in Washington. From the pilot-balloon observations, charts are constructed showing the wind-speed and direction at the various levels: for instance, one chart shows the wind-direction and speed near the ground, another chart shows the wind-direction and speed 500 meters above the ground and additional charts show the wind-direction and speed at the following levels: 1,000, 1,500, 2,000, 3,000 and 4,000 meters above the ground. The forecaster at Washington has the various charts before him showing wind and weather conditions prevailing over the United States within an hour and a half after the observations are made. From these charts he prepares the forecast of weather conditions for the various sections of the United States and at the same time prepares a statement of the wind and weather conditions at various altitudes along the various air routes for the use of aërial navigation. This service is already being used by the aërial mail service, and it is also used by the military flyers, as is evidenced by telegraphic requests received at various military meteorological stations for special reports on the weather and wind conditions when long distance flights are contemplated.

The problem of exploring the upper air currents over the Atlantic was at first thought insoluble on account of the absence of fixed bases, but the success of the Meteorological Service in developing its long-range propaganda balloons has now made possible the mapping of the upper-air highways across the Atlantic, for arrangements are being made to send up both from coastal stations and from trans-Atlantic steamers these

long-range balloons designed now for from two to three thousand mile flights, and adjusted to maintain a constant altitude and to drop in western Europe their records of average winds in these heretofore unchartable regions. The importance of this work for the future of aviation needs no emphasis.

The success which the Meteorological Service has attained would have been wholly impossible had it not been for the intimate and effective coöperation which has been extended to it in all of its projects by Director Marvin and the whole staff of the United States Weather Bureau. The chief credit for the work abroad should go to Major William R. Blair, commissioned from the Weather Bureau for the observational work with the A. E. F. For the success of the service in this country Captain Sherry and Lieutenant Waterman have perhaps the chief responsibility. Captain Murphy and Professor Fassig have, however, contributed very important elements.

V

SOUND-RANGING IN THE AMERICAN EXPEDITIONARY FORCES

AUGUSTUS TROWBRIDGE

THE following picture is not an imaginary one, but rather one of a very common occurrence throughout the entire period of the war on the long battle front which stretched from the Alps to the sea.

It is a dark, cloudy night and enemy shells begin to fall near an important point in the trenches or on battalion or regimental headquarters. There is a hurried report to our artillery and in a few minutes our own guns begin to reply with shells which rend the air or whine as they pass overhead toward some invisible mark five miles distant through the black night. Presently the enemy's fire begins to falter and then ceases and the infantryman, whose life may have been saved and whose comfort and efficiency certainly has been protected, may wonder how the artillery knew just where to direct its fire. He knows how it is done in clear weather; how the artillery maintains advanced lookout posts from which observations are made on the flash of the nearer enemy guns; that there are other and more elaborate lookouts on high ground or in trees or towers on the forward edge of woods from which accurate triangulation on the more distant hostile batteries may be made; but he knows that these cannot be the means employed in rain, mist or fog and he probably ends by dismissing the question with the thought that it was only a case of good luck.

The chances are that even his officers have no clear idea of

how the enemy guns are quickly located in rain, fog or mist; for it has been the policy of the general staff to keep very secret the details of a scientific service in which the Allies possess a very decided superiority over the Germans.

Let us look for a moment at what may be happening on the same night on the other side of No Man's Land. A German battery begins to shell an important cross-roads in the Allied back area in order to prevent the bringing up of munitions or fresh troops. Presently shells begin to drop from somewhere in France, but at first these are not close enough to make it sure that they are trying to "find" the German battery; then six or eight rounds fall to the left and behind the battery; then there follows a short pause and another series of rounds falls to the right and in front of the battery; another pause and the next group of rounds has crept closer and this goes on until the battery has become the center of a steady rain of projectiles which makes it impossible for the crews to serve their guns.

The German battery commander knows that the Allies are directing their counter-battery artillery fire by a means which he himself does not have at his disposal and he knows what that means is, for his Intelligence has published a number of pamphlets which describe it. He also has a set of instructions as to what measures to adopt if he suspects that the Allies are employing sound-ranging against him in order to render it less effective, but these measures are unavailing against the most improved form of apparatus operated by the Allies.

It is the purpose of the following article to explain in non-technical terms how the Allies applied certain acoustic principles to determine the position of enemy guns when the more usual and simpler visual means of observation failed because of bad weather or because the German batteries were hidden from view. It is in no sense the purpose to magnify the importance of American scientific achievement in the war, for the present writer, who as an American scientist has every interest in seeing that all due credit comes to his profession,

nevertheless feels that so far as the war in France is concerned, American science contributed far less along original lines than the general public has imagined. This is no slur on American science, for it nobly did its part toward bringing the war to a close, but it did it along lines already laid down by our Allies and it did it all the more effectively for that reason.

The Allies counted much on American ingenuity in bettering the existing scientific services and in devising new applications of science to accomplish new purposes, but both they and we fully realized the paramount importance of first establishing services as good as their own before attempting either to make radical improvements or to establish new services. At the signing of the armistice experiments were under way in America, many of which were nearing completion, which might have added new and valuable scientific services to the number already functioning in France, but the fact remains that at the cessation of hostilities all that had been done was the establishment of American scientific units which were modeled on those of our allies. The most important of the applications of pure science which were a wholly new product of land warfare were: the use of cloud and shell gas, the extremely brilliant application of chemistry in the construction of gas-masks, airplane photography, the scientific aids to accuracy in gunnery and bombing from airplanes, sound-ranging, search-light and listening devices for anti-aircraft defense, directional wireless, and camouflage. Practically all of the absolutely new applications of physical science to warfare on land are contained in this rather short list. These, of all the great number of inventions which have been proposed, it has been possible and necessary to establish on an engineering basis and to organize into services for all the armies of the Allies.

The effect of these few new applications of science on the character of the warfare on the western front was very far-reaching. Airplane photography, for example, not only completely revolutionized military map-making but also profoundly modified the methods of the army Intelligence and made neces-

sary the establishment of a large force for compiling and comparing data from photographs and for disseminating information to all the various interested services. The profound effects which were produced by the gas warfare were patent to every man on the front and the same was true to a less degree of the camouflage and some of the other services mentioned, but the very existence of one of these, sound-ranging, was not suspected by most of the troops engaged. This was not because it was in its way less important than the others or because it was working less effectively but rather because it was the policy of the Allies to shroud this particular scientific activity in the most complete secrecy. For this reason, even now not only the general public but also the majority of those who were over there knows very little of the methods and achievements of the sound-ranging service. As these methods possess a considerable scientific interest and as these achievements have been very creditable it is quite fitting that some account of them should be included in this volume.

HISTORY

After the first Battle of the Marne the operations on the western front soon took on the character of siege warfare; the artillery of both of the belligerents was augmented, especially as regards the larger calibers and the batteries took up well-organized positions carefully concealed for the most part from visual observation by the enemy.

The possibilities of visual observation had been vastly improved by the use of the airplane in war, but these were somewhat restricted both by the practice of camouflage and by the generally unfavorable atmospheric conditions on the western front. Experiments were therefore undertaken by the French in the autumn of 1914 with the object of ascertaining whether the location of hostile guns by means of sound waves might prove feasible. It was probably not expected that a high degree of accuracy would be attainable because of the disturbing effect of wind and temperature irregularities, but the desir-

ability of even a fairly accurate method of location and ranging which should not be interfered with by rain or fog and against which the practised camouflage should be unavailing was so obvious that the first successful attempts by the French in 1914 led quickly to the establishment of a ranging service.

Instruments of four very different types for recording the arrival of the sound of the enemy gun were tried out on various parts of the French front. By 1916 the majority of the French sound-ranging sections were equipped with standardized apparatus of one type. A school for the instruction of the personnel of the sections was also established in the back area.

The standard type of apparatus adopted by the French had the advantage of simplicity and the further advantage that it was for the most part an assembly of well-known commercial apparatus which had been in use in the field telegraph service of the French Army. These were real advantages since the French were obliged to use men in the ranging service who were often unfitted for more active service or for some of the other more highly technical services. There were, however, certain very serious defects in the French apparatus which prevented its adoption first by the British and later by the Americans for neither of whom were the advantages just mentioned so important as they were for the French.

By the end of 1915 the British had organized a sound-ranging service which employed a photographic recording instrument devised by a British subject, resident in France, Mr. Lucien Bull, and which had been tried out with success on the French front but which had not been officially adopted by the French. In the hands of Mr. Bull and Major Bragg, in technical charge of sound-ranging in the British Army, the original apparatus was perfected so as to combine reliability with ample sensitiveness and an extremely quick recovery so that sound ranging could be carried on without confusion during periods of relatively great artillery activity.

Shortly after the entry of the United States into the war — in June, 1917 — a French scientific commission arrived in

Washington with information regarding a number of the new scientific activities in the French Army. This commission reported that four radically different systems of sound-ranging were at that time in use in the French Army and recommended that an instrument of each of the four types be constructed in America from rough sketches which were furnished and that a comparative test of the four types be carried out at an artillery firing field. The members of the commission stated that such a test had not been carried out in Europe and that it was regarded as highly desirable that such a test be carried out impartially in America. The commission had data on the original Bull apparatus but not on the apparatus as perfected for the British; this was unfortunate, as it rendered the competitive test incomplete and the conclusions drawn from the test subject to revision later.

The present writer was charged with carrying on the preliminary test and the construction of a field-set of the type which should be judged most satisfactory. Before construction was started the writer secured permission to go to France to study the various systems in actual use in the field and so became aware of the progress which the British had made in time to stop construction on the type first decided upon and to start construction of apparatus in quantity of the Bull type and to insure that the experimental work in America be along lines determined by field rather than laboratory experience.

By the end of 1917 the first American troops assigned for the ranging-service were available from the replacements already in France. The original group of about forty enlisted men were given instruction by a small group of officers who had been trained on the British front in the theory and practical application of sound-ranging, and an American school was formed as a part of the Army Engineer Schools near Langres. All of the five companies which ultimately came to France to carry on the ranging-service (both sound and flash), were put through this school before they were sent to the front. The instruction covered a period of one month and the men

were thoroughly trained in the duties which they would have to perform, with apparatus identical with that which they would have later to operate. The school was situated in a country where there was excellent opportunity to reproduce field conditions. The men not only worked in day and night shifts as at the front, but were given practice in making rapid changes of position such as they might meet with later in a rapid advance or a forced retreat. A short course in the theory of sound- (and flash-) ranging was given to intelligence officers and to the artillery officers who from time to time were detailed to the engineer schools. The ranging school thus not only served the purpose of preliminary training for the ranging companies but also as a center from which information as to the possibilities, limitations, and principles of the new methods of ranging could be disseminated among the officers of the two branches of the service with which the ranging sections worked.

A descriptive pamphlet, of a confidential nature, on ranging was also prepared and distributed for the information of artillery and intelligence officers generally.

A supply depot of the highly technical material used by the ranging-companies was maintained at the school, and a system of quick delivery by light motor-trucks was set up between the depot and the companies operating at the front. During the period of about eight months (March to November, 1918) during which American ranging-sections operated, work never had to be discontinued, even temporarily, for lack of supply of the highly technical materials used by these sections. For a large portion of this period American sections were operating at widely scattered positions which made the problem of supply a difficult one.

ORGANIZATION IN THE A. E. F.

The ranging-service in the American Expeditionary Force consisted of two branches, the sound-ranging and the flash-ranging. One ranging-company was allotted to each American

corps, and such a company furnished two sound- and two flash-ranging sections, each section forming a unit capable of covering a front of about five miles. Since an American army normally consisted of five corps, this gave a battalion of five ranging companies per army, and this battalion, if necessary, could cover with both sound- and flash-ranging a front of fifty miles. An army of five corps is not likely to have to cover so wide a front as this even in defensive operations, while in offensive operations on a narrower front the reduction in the necessary number of the ranging-sections could take care of the increase in the number of men required to run a section under battle conditions. Under the conditions of trench warfare, four officers and from fifty-five to sixty men were found to be sufficient personnel for a sound-ranging section. One officer is in charge of the maintenance and repairs of the relatively large network of electrical lines running across the shelled area to the observation stations. Two officers are needed, besides the commanding officer, to supervise the work at the central or calculating station where three eight-hour shifts are maintained and from which reports of hostile fire or directions for ranging the fire of friendly guns are telephoned to the artillery information officer. On an active front two more officers and about twenty more men are needed. About one-third of the men in a section are needed for maintenance of the electrical lines of communication, another third for calculation, instrumental work and forward observation and the remaining third for transportation, supply, cooking, orderlies, etc. The policy adopted was to keep the minimum number of men necessary for proper observation at a section, with reserves at company and battalion headquarters ready to be sent where most needed.

PRINCIPLES OF SOUND-RANGING

Sound travels in still air at zero degrees centigrade, (the freezing point of water), at the rate of 330.6 meters per second (roughly 1100 feet per second). At 10 degrees cent. the

speed, to the nearest whole number, is 337 meters per second. The velocity is not only affected by the temperature of the air but also the *apparent* velocity is very markedly affected by the velocity and direction of the wind. It follows from this that a survey carried out by the means of sound waves, unlike a survey carried out in the ordinary manner by light waves, is subject to errors introduced by the lack of accurate knowledge of the wind and temperature corrections which it is necessary to apply to the data of observation. Furthermore there is a lack of parallelism between a light survey and a sound survey which will be evident from the following consideration. To locate a point on the ground by a light survey it is only necessary to secure an intersection of two light beams from two known points on a surveyed base line by the use of relatively small telescopes, while to obtain a location at all comparable in accuracy by means of sound it would be necessary to use instruments of prohibitively great size. Fortunately, however, advantage may be taken of the low velocity of sound compared to that of light to obtain a survey from *three* points without the use of listening apparatus of great size. This method entails the accurate measurement of the *differences* of times of arrival of sound at the three points. This, of course, requires the use of some form of accurate clock and precludes the use of human observers who are likely to differ so much in their reaction times that their results are only roughly comparable.

In still air at 10 degrees centigrade the sound from a gun moves out in a wave of compression and rarefaction which travels 337 meters per second. If the gun is at G and mechanical listeners electrically connected to a common timing

¹ The Germans employed a sound-ranging system with human observers especially trained and selected to have equal reaction time but the results obtained by the Germans fell far short of what the Allies accomplished. The German system was defective not only as regards accuracy but also as regards the speed with which results could be reported; what the Allies could do in two minutes took the Germans nearly an hour.

device are situated at M_1 , M_2 and M_3 and if, for example $G M_1$ be 3370 meters, the sound of the gun will reach M_1 in 10 seconds, and the front of the spherical wave will go through M_1 , N_2 and N_3 . This wave front moving with the velocity of 337 meters per second will reach M_2 later than it reaches M_1 . How much later is determined by the time it takes the sound to travel the distance $N_2 M_2$ (that is by $\frac{N_2 M_2}{337}$ seconds). Thus

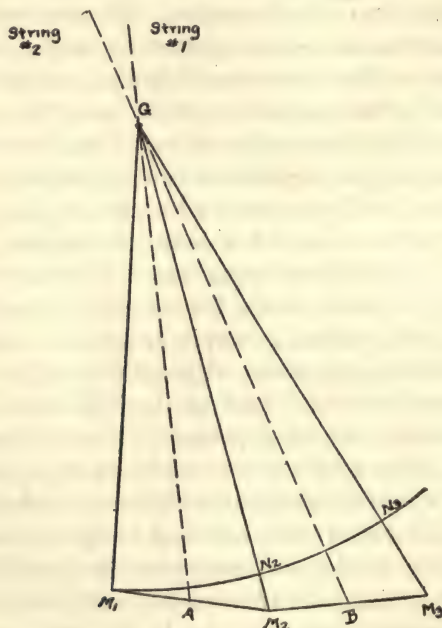


Figure 1

the *interval* between the arrival of the sound at M_1 and at M_2 will be $\frac{N_2 M_2}{337}$ seconds and the interval between the arrival at M_1 and at M_3 will be $\frac{N_3 M_3}{337}$ seconds. Suppose the distance $N_2 M_2$ were 33.7 meters, then the interval of time between the arrival at M_1 and at M_2 would be one-tenth of a second and

this would be what would be recorded on the timing device electrically connected with M_1 and M_2 . This interval alone would not serve to locate the position of the gun for there is a whole series of positions which the gun might occupy and still send the sound to M_1 a tenth of a second earlier than to M_2 ; in fact G might lie anywhere provided GM_2 were greater than GM_1 by 33.7 meters in the example chosen. Stated more mathematically, G must lie on a particular hyperbola having M_1 and M_2 as foci, for an hyperbola is a curve drawn in such a way that the difference of the distances from any point of the curve to two fixed points, or foci, is a constant (33.7 meters in this case). Now if G is not close to M_1 and M_2 compared to the distance between M_1 and M_2 , which is the practical case on the battle front, the hyperbola on which G must lie is practically a portion of a straight line which, if prolonged, goes through a point midway between M_1 and M_2 and thus it is possible to determine the *direction* from this mid-point to the gun. A plotting board may be prepared in advance which has a string pivoted on the mid-point A , and a scale on the edge of the board marked with hundredth and tenth seconds intervals. In the example taken this string would have to be set at the interval marked one-tenth of a second and the gun would be determined to lie on the ground at some point represented on the plotting board as a point lying under the string. Similarly, if the observed interval between the times of arrival of the report at M_2 and M_3 be laid off on a second scale for a string pivoted on the mid-point B the intersection of the two strings would locate on the plotting board the position of the gun on the ground. Naturally the plotting board must be very carefully prepared from an accurate survey of the positions of the listening instruments on the ground.

The location found on the plotting board will only be exact without correction if the temperature of the air is 10 degrees centigrade and if there is no wind. If there is no wind but the temperature is greater than 10 degrees centigrade the sound

will have traveled more rapidly than was assumed in the preparation of the plotting board and the intervals will thus be too small for the scale adopted in drawing the board. The amounts by which the intervals must be augmented or diminished if the temperature of the air be known are easily calculated and the strings may be set for the corrected intervals and the intersection then determines the true position of the gun as before. If a wind be blowing with a known velocity in a given direction it is only the components of this velocity which lie along the directions GM_1 , GM_2 , and GM_3 which will affect the times of arrival of the sound at the listening instruments; the observed intervals may therefore be easily corrected to what they would have been were there no wind and the plotting strings set accordingly.

The theory of the application of the wind and temperature corrections is an extremely simple matter and the application itself is easy and rapid because of the graphical method of calculation employed in the construction of the string plotting board. The real difficulty lies in an uncertainty as to what the true temperature and wind are, since the sound comes by a path inaccessible to observation. More than half of the path lies behind the enemy lines and the remainder lies in a region in which it is not permissible to attract the attention of the enemy by carrying on any unnecessary activities.

A very valuable study of the wind and temperature corrections to be applied to the observed data of sound-ranging was made by the British before the entry of the United States into the war and an empirical rule was found to hold that these corrections should be based on observations of wind and temperature made as near the front as convenient and at a height of fifty meters above the ground. In the American service the meteorological data were not available from army sources when the first sound-ranging sections went into the field in March 1918, so each section was equipped to obtain its own data.

There are other wind and temperature effects which are of

a qualitative nature and may very seriously affect the operation of a sound-ranging section, since corrections are usually not possible. If the wind be blowing in a general direction towards the enemy the sound of his guns may not arrive at the listening instruments because of a lifting of the sound waves as they

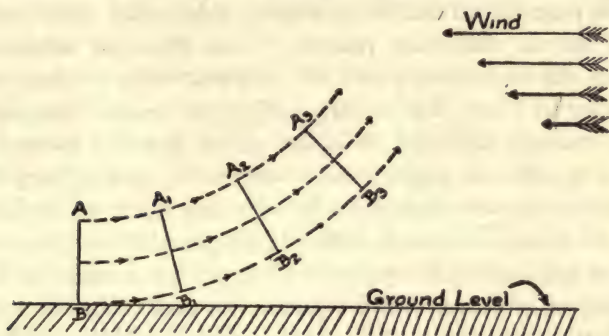


Figure 2

advance against a wind whose velocity is generally greater at the higher levels than it is near the ground. This case is illustrated in Figure 2.

If the direction of the wind is from the enemy guns the sound reaches the listening instruments, but it is prolonged

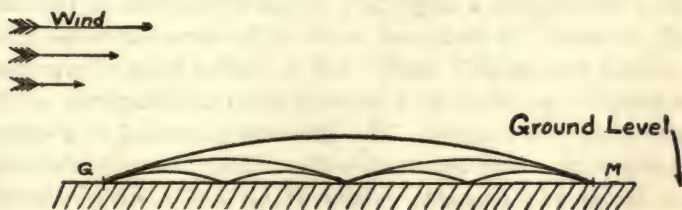


Figure 3

by reason of echoes from the ground and the result of this is that the time of arrival is not clearly marked. This case is illustrated in Figure 3. Echoes also occur because of temperature inequalities which cause reflection of the sound

from air strata of unequal density at various heights above the ground.

Three listening instruments electrically connected with a "central" or calculating station are theoretically sufficient to permit of a survey of the enemy batteries by sound; however, it is in practice advisable to employ more than three instruments for the following reasons: The electrical connections between the instruments and the time-recording mechanism at the "central" are unavoidably subject to considerable cutting by the enemy's shell-fire; it is out of the question to bury the lines to a sufficient depth to avoid all cutting and to bury them in a shallow trench renders the location and repair of the breaks which do occur, extremely difficult; the practice has been to lay the lines exposed on the ground and to provide a sufficient force of linesmen to ensure quick repairs. In order that the section may continue its work while such repairs are being made, six listeners instead of three are provided in the expectation that at least three will always be in working condition. If only the minimum number (three) of listening instruments are employed no estimate of the accuracy of a location can be formed whereas if six instruments be used the location is determined by the intersection of five strings on the plotting board; if these all intersect in a point the location is probably accurate whereas if they intersect in a large cat's cradle the location is probably badly in error. A study was made of the errors corresponding to certain typical cat's cradles and a general plan of reporting the probable accuracy of a location from the character of the intersection was adopted. The officer in command of a sound-ranging section thus reported to the artillery not only the location, target and probable caliber of an active enemy battery but also whether the location was probably accurate to fifty, one hundred or one hundred and fifty meters; these estimates were formed in a scientific manner and all of the various sections on the front employed the same method. After a considerable number of the enemy's battery positions had been captured it was possible to check up the errors of the in-

dividual sound-ranging locations with the results of a careful survey of the positions; it was found that the estimates of accuracy had been rather too conservative, for in none of the cases examined was the accuracy less than had been claimed

Fig.4

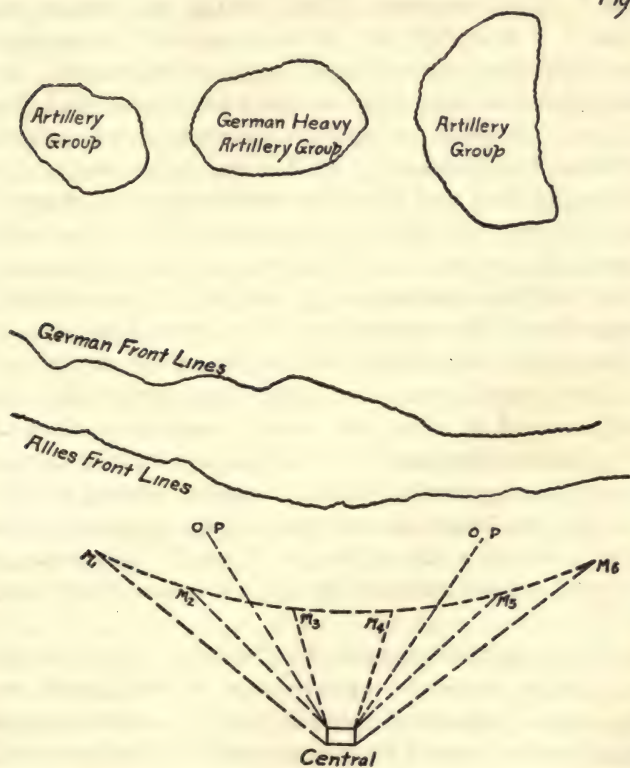


Figure 4

when the report was made and in the majority of the cases it was considerably greater.

A sound-ranging section consisted of six listening instruments at carefully surveyed positions on the ground; each of these instruments was electrically connected with a recording

photographic chronograph at a "central" or calculating station so situated as to entail the minimum amount of wire connection to the listening instruments. Each section had two advanced posts at which observers were on duty day and night in order to start the automatic recording mechanism at the "central" when necessary. The listening instruments were equi-spaced on a straight line, or more generally on an arc of a circle which was concave toward the enemy, situated a short distance behind the line of the advanced posts mentioned above. The distance between the listening instruments was generally about fifteen hundred meters so that the entire length of the sound-ranging base was about seventy-five hundred meters or slightly less than five miles. The employment of a regular base, generally an arc of a circle, was a highly important innovation which was introduced by the British; it rendered the interpretation of the records easy even when there was considerable artillery activity because the indications on the record which were caused by any one of the many guns which might be firing at about the same time were spread out on the record in a simple geometric pattern if the listening instruments were arranged on the ground in a simple curve. Owing to this it was possible to locate several guns, firing practically simultaneously, without a loss of time in correctly interpreting the photographic record delivered by the instrument at the central station.

The recording mechanism at the "central" consisted of an accurate timing device arranged so as to photograph on a moving strip of sensitized paper a series of lines about one-fiftieth of an inch apart; these lines were the shadows cast by a set of spokes of a wheel which was kept spinning in the path of a beam of light which fell on the sensitized paper; the rate of spin of the spoked wheel was governed by a tuning fork so that the shadows were cast on the paper with the greatest attainable regularity; the rate chosen was one hundred shadows per second so that the photographic paper had recorded on it across its entire width an extremely accurate time scale the

smallest interval of which was one one hundredth of a second; the tenth second mark and the entire second mark were made so as to be easily distinguishable from the others in order to permit rapid counting. The photographic paper employed was of the width of the standard moving picture film as this could be obtained quickly and at low cost both in Europe and America.

Superimposed on the time scale on the paper were six shadows evenly spaced across the width of the paper; these shadows were cast by six tiny moving elements of a specially constructed galvanometer. One of each of these elements was electrically connected to a corresponding one of the listening instruments of the sound-ranging base. When the sound of a gun arrived at listener No. 1 there occurred a slight twitch in the element No. 1 of the galvanometer and this twitch was photographically recorded on the moving paper strip. The time the twitch occurred could be read with an accuracy of at least a hundredth of a second because the record of the twitch and of the time were superposed on the same piece of photographic paper. When the sound arrived at listener No. 2 the element No. 2 responded and recorded the exact time as just described for No. 1 and the same was true for the other four elements. Thus if the mechanism were set in motion before the sound of the gun reached the listener nearest to the gun and was allowed to run until the sound reached the listener furthest from the gun the photographic record which was delivered, automatically developed and fixed, contained all the information necessary to calculate the gun's position; i. e., it contained the five *intervals* between the times of arrival at the six listening instruments. If, as generally, the recorder was run for twenty or thirty seconds, the burst of the enemy's shell was also recorded and its position could be reported to the artillery in one to two minutes after the gun had fired.

Figure 5 illustrates the type of record obtained from various types of German guns variously located with reference to the listening instrument. Figure 5 A shows the "twitches" on

all six recording elements due to the sound from a 15 centimeter howitzer situated very nearly equidistant from all six of the listeners. The vertical lines represent tenth second intervals. The hundredth second intervals which appear on the actual film have been omitted from the drawing. Figure

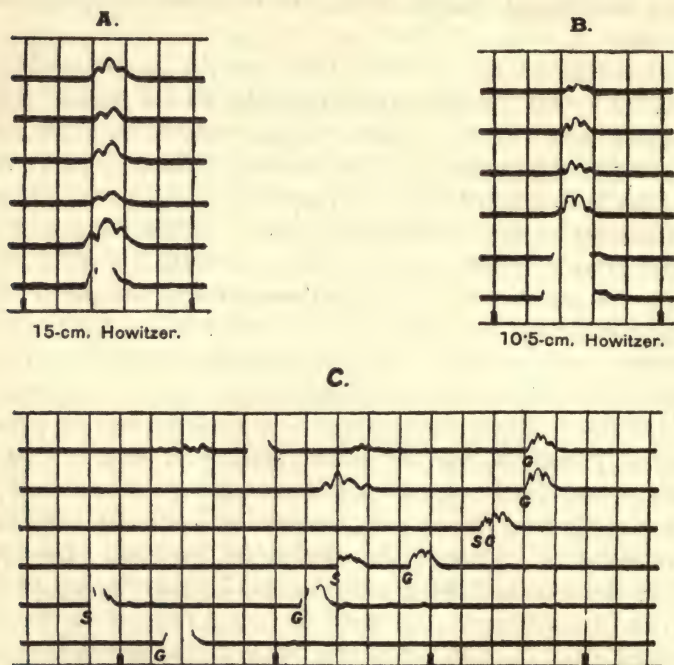


Figure 5

5 B is similar to A except that a wind was blowing from the left flank which caused the sound to be so loud on the right flank that the twitches of the lower elements are too rapid to photograph. Figure 5 C is the record from a high velocity gun situated towards the right flank of the sound-ranging base. The portions of the record marked S are due to the bow wave of the shell as it passes over the various listening instruments while the portions marked G are due to the muzzle wave of

the gun. It is, of course, this latter portion of the record that is used to calculate the position of the gun. The time intervals between S and G serve to identify the caliber of the gun.

The listening instruments were grids of very fine wire electrically heated and mounted in the narrow neck of bottle-shaped containers. When the sound from a gun arrived at the container, air was forced in and out by the pressure changes existing in the passing sound wave; the air rushing in and out cooled the hot wire mounted in the neck of the bottle and this cooling disturbed the flow of the electric current used to heat the wire, and the variation in the flow of current was what actuated the moving part of the galvanometer at the "central" and caused the twitch in the shadow recorded on the moving photographic paper. The listeners were rendered purposely insensitive to loud but high-pitched noises like rifle fire, etc., but purposely very sensitive to grave and sometimes almost inaudible sounds like heavy caliber artillery fire; in fact, for the purpose for which they are designed the listeners were superior to the human ear and were able to pick up German guns as far in the rear as guns were likely to be placed. Very often a gun — the report of which had not been audible — was found on the same record with a nearer and audible gun.

The timing device at the "central" station was run continuously day and night but the remainder of the apparatus was run only when firing was taking place; for this reason the apparatus was electrically controlled by observers stationed near the front line trenches; these observers had certain groups of enemy artillery assigned to them for surveillance and they were instructed to start the recording mechanism whenever they heard firing from their assigned areas. There were generally two or more forward observation stations (marked O. P. on Figure 4) to each sound-ranging section, so chosen with reference to the lay of the land, that no enemy-firing on the five mile front could take place without attracting the attention of at least one of the groups of forward observers.

A typical record not only contained data from which the

position of the enemy gun could be located but also contained data from which the location of the burst of the shell could be calculated; thus both the range and the time of flight of the shell were known. In the case of guns employing fixed ammunition charge a knowledge of these two quantities was sufficient to determine the caliber of the gun since the values of the muzzle velocities of many of the German guns were well known to the Allies. Even in the case of guns not employing fixed ammunition charge the fact that the burst of the shell could be located enabled the officer in charge of the section to recover fragments of the shell on which to base an estimate of the caliber.

The possibility of an estimate of the caliber of the enemy guns was one of the unique features of sound-ranging. Another important feature was the ability to locate guns which were brought up by the enemy in preparation for an attack and which were therefor not used in the period preceding the attack in order to insure an element of surprise. Such guns usually fired but one or two ranging shots and if they were well concealed usually escaped detection by ordinary means; many such guns were located by sound-ranging when they fired their first, and often only, ranging shot.

The location of the enemy artillery formed only one part, though the more important part, of the routine work of a sound-ranging section. When, because of bad weather, aerial or other visual observation was impossible the sound-ranging sections were called on to correct the fire of the friendly artillery on enemy objectives either to silence the fire of batteries or to harass the enemy traffic in the back areas. In the case of silencing the fire of an enemy battery which had just fired, sound-ranging was very effective. The following consideration will show why this was so: suppose an enemy gun has just fired and that a record has been obtained by the sound-ranging section; to obtain an accurate location it is necessary to apply temperature and wind corrections to the observed data and it is the lack of accurate knowledge of the wind and

temperature which causes errors in the location; suppose that instead of attempting to *locate* the gun the approximate position is reported to the friendly artillery and a shell is thrown immediately somewhere near the enemy gun and a sound-ranging record is taken of the burst of this shell. If, by chance, the shell had hit the gun the sound-ranging records of the gun and of the burst would be identical, for whatever effect wind and temperature had had on the one record it would also have had on the other. Even though the first shell does not hit the gun it will be near enough so that its *relative* position to the gun may be accurately calculated from the *difference* of the two records. If the sound-ranging section commander reports the first shell as so many meters left and so many meters short, for example, the battery commander may correct round after round in this manner until a direct hit is obtained. A technique of rapid calculation was devised which permitted the simultaneous correction of the fire of all four guns of a friendly battery firing salvos. The fall of individual rounds was in practice not reported though they were of course observed but rather the mean point of burst of six or eight rounds of each of the guns was reported; the battery commander made his corrections and another series of rounds was fired and new corrections were applied and this was generally sufficient to make it worth while to fire for effect. This method of ranging was only employed when the simpler visual methods were impossible as it necessitated a partial suspension of the normal work of the sound-ranging section which was the location of active enemy batteries.

Ranging on an objective other than a gun which had just fired was of course subject to the inaccuracies due to wind and temperature. However, in this case the objective was generally a large one such as an ammunition dump, rest billets, cross-roads, or the like, so that a high degree of accuracy was neither sought nor needed.

ACCURACY OF LOCATIONS

After the capture of the St. Mihiel salient and again after the armistice, surveys were made by the army topographers of the gun positions which had been located by sound-ranging and the data from these surveys were used by the officers in charge of the sound-ranging sections to determine what errors had

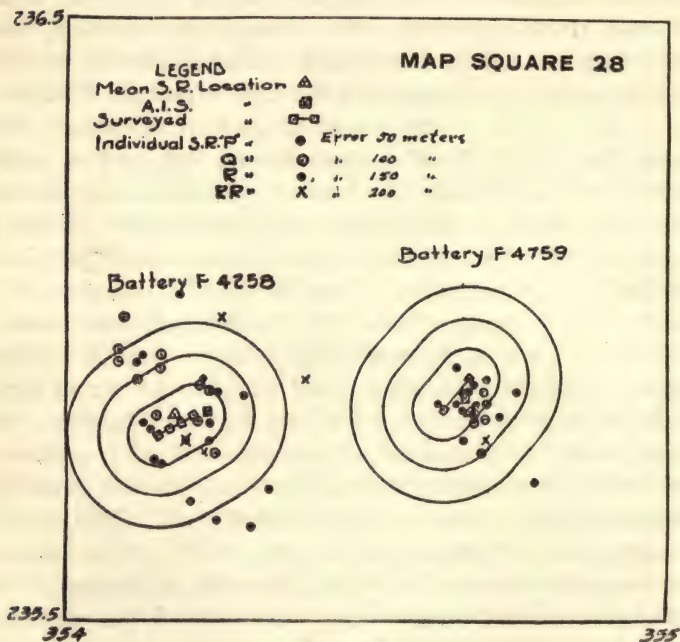


Figure 6

been made in their locations. This study brought a number of interesting results to light, some of which are of theoretical interest to physicists and meteorologists and some of which are of practical importance in pointing the way to improvements in any future sound-ranging service in the army. The chief result of practical importance was that the average value of a small number of locations obtained under different weather

conditions, is of a surprisingly high order of accuracy. The error is often less than ten meters and rarely more than twenty-five meters at a distance of from five to eight miles. The reason for this high order of accuracy of the average is probably the following: Systematic errors, such as those due to a careless survey of the sound-ranging base or to errors in the timing device, etc., are practically non-existent and all errors are haphazard in character. The relative excellence of each location of a series may be judged from the character of the intersection on the plotting board as described earlier in this article so that a fairly correct weighted average may be formed by counting locations, estimated as correct to within fifty meters, three times, those estimated as correct to within one hundred meters, twice, and those to within one hundred and fifty meters, once. Whatever unsystematic error due to wind and temperature has been introduced will affect the weighted average value far less than it affects the individual values, for such errors will tend to cancel each other's effect.

As a result of the study of the errors in the sound-ranging locations of scores of enemy batteries it appears that the section commander should report to the artillery the average of all previous locations of a battery rather than the latest location or even the best location as judged from the character of the intersection of the strings on the plotting board. (There are many instances showing that the average of five or more locations, no one of which was correct to within 150 meters, was accurate to within 50 meters.) Of course in mobile warfare averages should not be taken nor should they be taken in position warfare if there is any reason to suspect that the gun is not occupying a fixed emplacement.

The great accuracy of the average of a series of sound-ranging locations was not suspected during the war even by those engaged in this service; had it been recognized an incident like the following would have been impossible. In the St. Mihiel sector there was an enemy battery position which was repeatedly reported by sound-ranging as active. The

average of eight locations showed it to have the map coordinates, $x=350930$ meters and $y=234700$ meters; subsequent survey showed that the middle of the battery actually had the coordinates, $x=350920$ and $y=234710$. The error amounted to 16 meters (in x) too far to the East and 10 meters (in y) too far to the South or about 19 meters actual error on the ground. This battery had eight gun pits, six of which had been recently occupied; nearby were deep, safe dug-outs and the whole position was well designed and executed; it had never been shelled by our artillery as it had never been listed as an active battery. About two hundred meters away from this very active battery was an emplacement which showed up clearly on the airplane photographs but which an examination of the ground, after the position had been captured, showed had not been active within at least a year. This inactive battery was listed by our artillery and it was assumed that the locations reported by sound-ranging of the really active but concealed battery were incorrect locations of the visible but inactive battery. Had either the artillery or the sound-rangers had a proper confidence in the accuracy of the sound location the German gunners would have had need of their deep safe dug-outs and our own lines would have been shelled less. Instances like the above were not common, however, and, generally speaking, the artillery made full and efficient use of the data supplied by sound-ranging. The surveys brought to light full confirmation of the theoretical considerations on the accuracy of the individual locations; thus, errors in range were always greater than errors in line and errors of both kinds were less when the gun was opposite the middle of the sound-ranging base than when it occupied a flanking position. Observations on guns lying more than one kilometer outside the perpendiculars erected on the ends of the chord of the base may be quite worthless as regards the determination of the range though still quite accurate as regards the determination of the line. This was predicted from geometrical considerations and in consequence it was the practice for some time

before the close of the war to locate enemy guns by employing two or more sound-ranging sections working together, so that each might give an accurate determination of line and by combining these to obtain an accurate determination both of line and range.

An idea may be gained of the *amount* of artillery information supplied by the sound-ranging sections from the following figures taken from a report of the artillery information officer of one of the American Corps. This officer had as sources of information American sound-ranging sections, and American and French flash-ranging sections. During a period of rapid advance 425 separate locations of enemy batteries were made; of these two American flash sections reported 63 per cent., three French flash sections 16 per cent. and three American sound sections 21 per cent. In a period of two weeks when the advance had been temporarily checked by the enemy the total number of locations was 392 and the percentages were: three American flash sections reported 38 per cent., two French flash sections reported 8 per cent. and three American sound sections 54 per cent.

In another and very active sector, where there was but one American sound section and one American flash section, the figures were: during a period of three days preparation for an advance, sound 22 locations, flash 22, balloons 0, aviation 0. During a period of sixteen days rapid advance, sound 4, flash 46, balloons 30, aviation 15. During a period of four days of stabilization, sound 6, flash 34, balloons 13, aviation 15. These figures are fairly characteristic and bring out clearly the relatively great importance of sound-ranging during the stationary warfare and of visual observation during actual attack. This was to be expected as sound-ranging was devised to meet the peculiar conditions of trench warfare. When, in the spring of 1918, it became apparent that a more open warfare was beginning, the sound-ranging sections were trained and equipped so as to become as mobile as the artillery of the heavier calibers but they never were able to get in action so

quickly or remain in action so long as the flash-ranging sections whose equipment was lighter and could be more quickly set up than that of the sound-rangers.

Sound-ranging was a product of the recent war. Whether it will prove useful in future wars is an open question but its usefulness to the Allies in the recent war was beyond question for, due to it, they possessed a marked advantage over their enemy in being able to locate and silence hostile batteries under conditions where all other means failed.

VI

WAR-TIME PHOTOGRAPHY

HERBERT E. IVES

BEFORE the great war, photography had figured but little as a military aid. It was used principally for making records; pictures of men and equipment, camps and battlefields, as in the famous Brady photographs of our Civil War. In quite recent wars some actual views of battles while in progress have been produced, with men and artillery in action. These were made possible by the practical development of instantaneous photography, and were due to the enterprize of the newspaper photographer catering to a public accustomed to get its news as much through photographs as through headlines. But the use of photography as an essential to the preparation as well as to the carrying out of military tactics is a development of the last war, as peculiar to it as is the development of the airplane. It is in fact in the airplane that the photographic camera has developed from a mere recorder of minor aspects of battles already lost or won, into the chief guide to their fighting and a really important military weapon. Any account of war-time photography must therefore be devoted largely to this newest form, photography from the air.

But we must not infer, because airplane photography has completely outdistanced all other kinds in military application, that the services of the less novel forms of photography have been small. On the contrary, the use of photography for securing records, for instruction, and in apparatus for the most diverse purposes — for instance in the sound-ranging of big guns — has been on a scale that would have warranted remark

merely from the standpoint of the magnitude of the service rendered. By way of record of American participation in the war we have photographs showing every structure erected in France, beginning with the docks of debarkation, and leading on up to gun emplacements at the front. All the details of modern warfare are preserved for future information and instruction; how trenches are built, how barbed wire is wound and supported, how telephone lines are strung, how gas attacks are launched and met, how guns are camouflaged. Thanks to photography there can henceforth be no excuse for ignorance of the full meaning of waging war.

The most novel feature of this record work is probably the use of the moving picture, which has practically come into being since the Spanish War and the Boer War. Through its use vivid records of all military operations are available in our war colleges for instruction and study. Preparation, training, and even "going over the top" are all faithfully delineated. Just as in the industries moving pictures are furnishing the most valuable records of construction methods and operations, so it has been in the war. Take, for instance, that real epic in cinematography, the story of the 14-inch naval guns; the construction of their railway mountings in Philadelphia, their transportation across the ocean, their assembly at a French port, their cautious creeping over French railway bridges, their detours around the too short French tunnels, until finally we see them in action against the Metz-Meziers railway. It may well be questioned whether the only adequate history of the war will not after all be the photographic one.

Other war-time uses of moving pictures must not be overlooked. Instruction in the use of machine guns, trench mortars, even in the handling of an airplane, has been made more vivid and more interesting, and so more easily grasped by the student when given through clever moving pictures. And their help in keeping up the morale of the men by supplying healthful amusement must by no means be forgotten, with a Y. M. C. A. budget for moving pictures of nearly two and a half millions.

Of the many applications of photography to military instruction one of the most striking and novel is the "camera gun," devised to train aviators in machine gun marksmanship. As at first worked out this consisted merely of a camera mounted on the machine gun support and capable of one exposure at a time. As finally improved and produced by an American manufacturer, this consists of a camera attachment to the Lewis gun which copies in every respect the behavior of the gun itself. Not only may single exposures be made but even "bursts," if the trigger is held back. On the pictures is impressed a target, to show how nearly the aim was correct, while in the latest form a clock dial is incorporated, so that when two aviators return from practice, they have a complete record not only of the number of hits, but also of who made the first "kill."

The chief photographic novelty of the war, aerial photography, owes its existence and rapid development both to the extensive use of the airplane, and at the same time to the very limitations of the plane. The chief function of the airplane is reconnaissance, the gathering of information on enemy military dispositions and movements; and it is this new all-embracing point of view which the air gives that has enabled the airplane to well-nigh revolutionise warfare. But it was early found that the human eye was quite unequal to the opportunities presented by the plane. More could be seen in a single glance downward than could possibly be remembered. Then later, as the flying was driven higher, the magnification given by the unaided eye was insufficient; the use of camouflage made necessary minute study of the view; and last but not least, the attention of the observer had to be given more and more to the military duty of defending the plane against "the Hun in the sun." All of these problems were met in a truly ideal manner by the use of photography. A single exposure with a long-focus camera produces a record faithfully depicting in an instant every detail of a large area in a form eminently suitable for study and general dissemination. From being a happy

experiment, aerial photography grew to be one of the main activities of the air forces. The war had not been in progress a year before the aerial photograph was the indispensable guide to all military operations. Enemy lines were completely photographed each day or even oftener. Negatives to the number of scores of thousands were made every month by the Allied armies, and from these, toward the end, half a million prints (in round numbers) were distributed each week to intelligence officers, to artillery headquarters, even to infantry company commanders to guide them in their local operations. So searching indeed did aerial photography become that as the war drew to a close all troop movements had to be made at night or under cover of bad weather. Elaborate attempts to camouflage batteries and fixed structures against the eye of the camera were met by the development of a corps of experts in a new art, the interpretation of aerial photographs.

The technical problems to be solved in the development of photography from the air were numerous.¹ Practically every resource of scientific photography had to be pressed into service and carried to further development by intensive research before aerial photographs with the necessary quality were procurable. As might be surmised, the foremost problems to be met were those introduced by the altitude, the speed, and the vibration of the new camera platform. The great altitudes reached by army reconnaissance flying — 18,000 to 20,000 feet — brought demands for lenses of very long focus and for combinations of sensitive plate and color filter to pierce the layer of haze almost always present on the earth's surface. The speed of the battle plane, sometimes as high as 150 miles an hour, when considered with respect to the earth, demanded lenses of large aperture and shutters capable of giving extremely short exposures in order to prevent blurring due to the motion of the image. The vibration from the engine necessitated not only

¹ For a comprehensive account of the technical aspects of aerial photography see "Airplane Photography," by the present writer, published by J. B. Lippincott & Co.

short exposures but adequate anti-vibration mounting of the camera.

Before taking up these problems one by one, let us look at the various types of photograph required. The simplest picture of all is produced by the process called "spotting," which consists in taking a single photograph of some important detail, such as a trench or a battery. (Figure 1.) Pictures of this sort were usually made with as long-focus lenses as possible, in order to secure large magnification. For this purpose cameras of as great focal length as 120 centimeters figured as a regular part of aerial photographic equipment.

Next come strip or mosaic maps made by a series of successive exposures, at such intervals as to overlap by a quarter or a third of their length. These photographs showed trenches, railways, large manufacturing plants, or other extended areas of military importance. (Figure 2.)¹

Both these types of picture were "verticals," that is, made with the camera pointing directly downward through the floor of the plane. "Obliques" were pictures taken with the camera at an angle. At first made with hand-held cameras, these were later taken by cameras slung in the plane at the desired inclination. Obliques closely resemble views made from high buildings. They show what the verticals do not, the elevations and depressions of the terrain, and because of the natural appearance presented by objects so photographed and because of their ease of interpretation, they were of great value during the preparation for local attacks.

Last of all come a class of pictures which may probably be claimed as an entirely new development due to the war. These are aerial stereoscopic views, produced not with two lenses separated by the distance of the eyes apart, as are ordinary stereograms, a method which, at flying altitudes, would give practically no relief, but with a single camera taking successive exposures separated sometimes by a few seconds, often by a

¹ Acknowledgement is made to the Air Service of the United States Army for figures 2 and 3.

goodly fraction of a minute. The result is a pair of pictures with points of view so separated that the stereogram when placed in the stereoscope presents the earth as it would be seen by a giant with a head a hundred feet or more in width, that is, with all the elevations and depressions showing in magnificent relief. Stereo aerial views, both verticals and obliques, were of the greatest importance in the detection of irregularities of level, in differentiating shell holes from "pill boxes," and in piercing the devices of the camoufleur.

The airplane camera required merely for spotting is a comparatively simple affair. No provision is needed for focussing since the objects to be photographed are always at photographically infinite distance. All that is necessary is a lens, a box as little subject to expansion and contraction as possible in the extremes of temperature met from ground to upper air, a shutter, and a plate holder. These essentials of an aerial camera, lens, shutter and plate, may profitably be considered in detail before touching on the more complicated types of camera demanded by mapping or by stereoscopic photography.

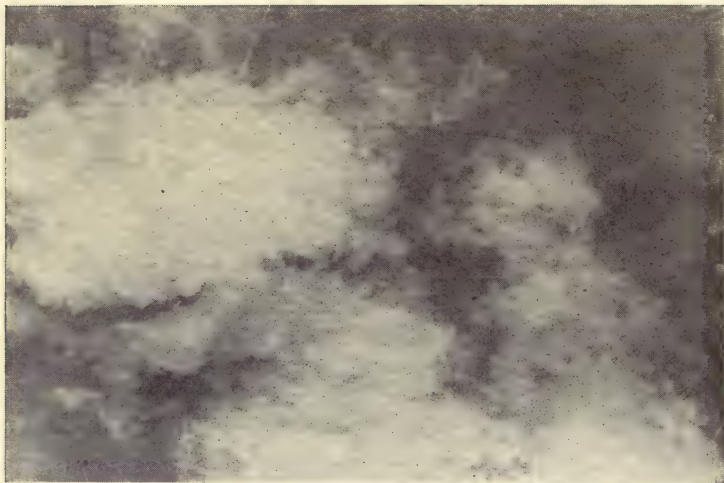
The lens should be of the anastigmatic type, covering a large flat field with microscopic definition, and should have the largest possible aperture, preferably not less than $F/4.5$. Lenses meeting these requirements had already been developed before the war and were in fairly common use for the smaller sizes and foci (up to 8 inch), but almost exclusively as a German product, due to the Jena optical industries. As a temporary measure, all available lenses of this kind were commandeered by the Allies for aerial use. Soon, however, flying was forced to 10,000 feet and over, and the pictures obtained with such lenses were too small. This fault was partially met in the British service by the regular practice of making enlarged prints from their standard 4 x 5 inch negatives. But this was not nearly so satisfactory as the process of contact printing from negatives secured by long-focus lenses. The efforts of the Allied lens manufacturers were, therefore, directed toward the production of lenses of a standard focus of 50 centimeters, capable of



Figure 1. Example of airplane photograph. Trenches, concrete dugouts and machine gun emplacements along the Yser River



Figure 2. The method of building up a mosaic map from a large number of overlapping serial photographs



View taken at 10,000 feet altitude, without color filter



Similar view taken at the same time on color sensitive plate through yellow filter, showing penetration of haze

Figure 3

COLOR FILTERS IN AERIAL PHOTOGRAPHY

covering a plate 18 x 24 centimeters in size. Their problem lay chiefly in securing optical glass, of which the Germans had almost a monopoly.

The optical glass problem is one which the Allies collectively did solve, but in so far as the dense barium crown glass required for modern photographic lenses is concerned, the greatest success was attained by the French and English, the latter indeed now bidding fair to oust the Germans from their primacy in the optical industries. While the American optical glass development did not succeed in producing the greatly desired dense barium crown, American manufacturers were able to utilize some substitute glass, and, by using English glass, developed new lens formulae admirably adapted to aerial use, so that lenses in satisfactory quantities were produced of 50 centimeters focus, of aperture F/6.

It is one of the severe limitations of airplane photography (but not of photography from dirigibles) that all exposures must be strictly instantaneous. Calculation shows that the conditions are rare when a speed of less than 1/100 of a second may be used without fatal blurring. And the faster the plane, and the lower it flies, the faster does the image move on the plate, and the quicker must the shutter act.

The common type of shutter used on the smaller commercial cameras, situated between the lens elements, was not suitable for airplane use, because it could not be made in large sizes; nor was it at all efficient at high speeds. There was, however, already at hand the focal plane shutter, a rapidly moving slotted curtain, traveling close to the plate, originally developed for the photography of rapidly moving objects on the earth's surface, such as race horses and automobiles. With very few exceptions all aerial cameras were equipped with shutters of this type. But the existing designs were found to be defective in many respects. The speeds developed were insufficient; the means for varying speed were inadequate. Most common of all, the speed was greatly different at the beginning and at the end of the travel across the large plates used, so that strip

or mosaic maps would be grossly uneven at the junction of their constituent prints.

Here, as in many other cases, the severe requirements set by this new form of photography led to intensive study, resulting in detail improvements which have reacted to the advancement of photography as a whole. Improved designs were worked out, in particular one by the American Air Service, which resulted in giving speed and regulation of speed much beyond anything heretofore attained.

The sensitive plate is, of course, the crux of the photographic problem. Needless to say, high speed is essential in aerial work. Careful research developed, however, that mere speed, as ordinarily measured, is not alone sufficient. Aerial views are apt to be much under-exposed, and in addition there is but small contrast of brightness in objects on the haze-covered earth. Consequently it is desirable to have a photographic emulsion that will develop as much contrast as possible, with short exposures — a combination of qualities not usually found.

In addition to speed and contrast requirements comes the very important one of color sensitiveness. Photography from high altitudes means photography through a thick layer of aerial haze. Because of its general bluish color, this haze appears much thicker to the blue-sensitive photographic plate than it is to the naked eye. To pierce this haze it is imperative to use color filters of a general yellow hue, and with these it is necessary to employ plates sensitive to green, yellow and red. The Germans used very generally a plate of extraordinary green sensitiveness, greatly superior in that respect to anything produced by the French or the English. This plate one of the American manufacturers was able to match and indeed to surpass, thus producing what was undoubtedly the best orthochromatic plate used in the war.

Probably the greatest achievement in photographic plate making during the period of the war was the production of a new panchromatic (sensitive to all colors) plate by one of the English manufacturers, using new sensitizers developed by

Professor Pope of Cambridge. These plates possess the unusual characteristic of being more sensitive to red than to blue light, and possess at the same time unusually high speed. Produced first in the spring of 1918 these plates proved a God-send to the Allied aerial photographers in the dull days of the last great offensive, when the plates formerly employed by them were only usable a few hours near noon.

Closely connected with the matter of color sensitiveness in the plate is the question of color filters, to pierce the veil of haze characteristic of the view from high altitudes. How important is the use of a filter is shown in Figure 3, where the picture taken at 10,000 feet without a filter is quite useless, while its companion, taken at the same time but with a filter, shows the roads, trees, and other details clearly. Here again the Germans were at an advantage both because of their mastery of the manufacture of colored glass and also because of their well-developed dye industry. In this connection it is to be noted that the ordinary yellow filter intended to produce orthochromatic effects is not what is required to pierce haze. The requirement here is for a comparatively abrupt absorption of the blue of the spectrum, which will cut down the green but little and so leave the filter as efficient as possible.

The problem of producing filters of the required efficiency, through which the exposure would not have to be increased more than two or three times, was completely solved for the American Air Service by two developments. The first was a yellow glass produced by a leading glass manufacturer, and the second a new dye, the "EK" (from the name of the company in whose laboratory it was developed) with which gelatin discs were dyed and afterward mounted between glass plates to form a highly satisfactory filter.

The simple camera above described, which sufficed for spotting, was subject to many improvements aimed at simplifying its manipulation, increasing the speed of operation, enlarging its plate capacity, and — a vital point in the military plane — making its operation as independent as possible of the attention

of pilot and observer, leaving them free for other duties. Plate magazines, carrying from six to a dozen plates, operated by a simple to-and-fro motion shifting the exposed plate behind the pile of unexposed, were generally used by the French and Germans. The English early designed and used to the end a system of two magazines, one above the camera containing the unexposed plates, another to one side and lower, over which the exposed plate was shifted and allowed to drop. Cameras of this type, known as the "C" and "E," operated by hand, were ultimately followed by the "L," in which the operation of shifting the plate and setting the shutter was performed by a wind propeller. In this "semi-automatic" camera the pilot or observer had merely to pull the exposing lever at the appropriate instant, after which the camera set itself ready for the next exposure. These cameras, using 4 x 5 inch plates, formed the greater part of the equipment of the English Air Service, and close copies were manufactured and used in large quantities in the training of some thousands of American aerial photographers.

The demand for completely automatic plate cameras, which would require no attention save starting and stopping, was perhaps most nearly met by the French de Ram camera. In this was embodied a rotating magazine containing 50 plates, the lower one of which was exposed, dropped off and picked up by the top of the magazine as it rotated. Cameras of this general design were under construction in considerable numbers in America at the close of the war, and promised to be the most complete and satisfactory plate camera yet devised.

A serious limitation to all plate cameras for aerial use lies in their weight and bulk. Thus the de Ram camera above described weighs, with its load of plates, about 100 pounds, and stands over three feet high. Such a weight seriously interferes with the balance and ceiling of the ordinary two-passenger reconnaissance plane, and is quite out of the question as an extra load in a single-seater scout. This matter of weight and space became so aggravated by the general adoption of 50

centimeter focus lenses and 18 x 24 centimeter plates that intensive study was turned toward the possibilities of celluloid film in roll form. This, from its lightness and small bulk, would appear to be the ideal medium for aerial photography.

Several interesting problems were met with in the development of aerial film cameras. One was that of holding the large film flat during the exposure. This was met in several different ways. One method was to use a glass plate pressed against the films, and since the plate was made of yellow glass, it could at the same time be utilized as a color filter. Another method is the use of suction through holes in the camera back, the suction being produced by pump, Venturi tube, or bellows.

Another problem of some seriousness was caused by the production of static electricity from the friction of the celluloid film against the camera parts. This is especially frequent at high altitudes, in cold dry air. It results in tree-like discharges across the face of the film, easily mistaken for trenches or paths, if indeed they do not obliterate the whole picture. This is a trouble which used to occur in moving picture cameras, to be finally met by metal construction and by grounding the apparatus — the latter an expedient not permitted in the airplane. After considerable experimentation it was found that this trouble could be entirely overcome by covering the suction-back with coarse grained cloth impregnated with graphite, whereby the fibers were turned into small electrically conducting paths, leading off the electric charges as soon as formed.

The film camera embodying these features promised in time to supersede the plate camera for aerial work, although it did not materialize in time to be actually used in the great war. The chief outstanding problem in the use of the film is presented by its development, washing and drying in the huge rolls of 100 or 200 exposures which it was expected would be needed for reconnaissance work. Special mobile photographic laboratories, consisting of truck-and-trailer dark and printing rooms were already part of the regular photographic section outfit at the front, equipped to develop plates in a few minutes

after their delivery and to furnish thousands of prints over night. With the advent of the film camera an additional trailer equipped with a special film-developing machine was planned. It is indeed probable that had the war continued much longer the automobile photographic train might have been supplemented by railway photographic laboratories, so extensive had photographic operations become.

The proper mounting of the camera in the plane is of prime importance. The first cameras were held in the hands, but this soon became impossible, due both to the size of the cameras, and to the airman's need for freedom to handle machine gun and radio. Cameras were next "screwed" to the framework of the fuselage, a method of support which proved quite unsatisfactory, as half the pictures would be ruined by the vibration set up by the engine. Following this, various supports of rubber and springs were devised along more or less scientific lines, a chronic difficulty being the inadequate space available for the camera and mounting.

Finally an accurate method of study and test was developed in the English Air Service, on the basis of which eminently satisfactory mountings have been devised. This method consists in flying over a light on the ground, either at night (or else by day, with the light located in a dense wood), the shutter of the camera being left open. There is thus obtained on the plate a trail, smooth if the camera is steady, wavy if it is vibrating. By means of a second intermittent light, flickering at known speed, the duration of each kink in the curve may be learned, and the suitability of the mounting evaluated accordingly.

Comprehensive tests of all kinds of mountings, supporting the camera at the bottom, at the top, loosely and tightly, show conclusively that the best form of mounting is that which supports the camera in the plane of its center of gravity (which should not change as the camera operates), the supporting parts being bedded in soft rubber or springs.

After the aerial picture is obtained comes the question of its

interpretation. At the best of times the vertical view presents all objects in an unfamiliar aspect, while in modern warfare the arts of camouflage are enlisted to render interpretation harder yet. In aerial photography the greatest foes to camouflage are stereoscopic pictures, and the fact that the photographic plate is differently sensitive to colors than is the human eye. Thus often gun coverings and concealed dugouts, not noticeable by the observer as he flies over, show clearly in the photograph he brings back, since the camouflage paint is a visual but not a photographic match with its surroundings. Camouflaging pigments had, therefore, to be tested photographically, and in turn plates and color filters were sought which would defeat the efforts of the enemy camoufleur.

The every day problem of the interpreter of photographs was to detect changes of any sort—the substitution of artificial trees with concealed listening posts for real trees; the removal of sod to be used elsewhere for camouflage. For this purpose photographs made on different days were laboriously compared, side by side. Even when this was done, minute but important changes would be missed, a common failure which led to several proposals to facilitate such comparisons. One was the use of the “blink microscope” in which the two pictures were viewed successively in the same position, any change showing as a fluttering or blinking in the scene. In another ingenious scheme, adapted from the astronomical method of searching for moving asteroids, a positive made from one negative is laid over a negative of the same subject made at another time. If no change has taken place the two merge to a neutral gray. If anything in the view has moved, it stands out in striking contrast with the undisturbed parts.

In this brief sketch of war-time photography chief emphasis has been laid on the contribution of photography to the winning of the war. Reciprocally the demands of war have worked to advance to no inconsiderable degree the science of photography. This will be manifested, if in no other way, in the production of photographic apparatus of greater accuracy and reliability

of performance. The impetus given to research by the quest for emulsions of greater speed and sensitiveness has already resulted in unexpected progress, and this research may be relied upon to bring forth even greater improvements. The addition of an entire new department — aerial photography — is undoubtedly the greatest advance due to the war. It opens up a new territory, and appears destined, quite apart from its wide pictorial uses, to enormous usefulness in mapping. It promises indeed quite to revolutionize our present methods of charting the earth's surface.

VII

OPTICAL GLASS FOR WAR NEEDS

HARRISON E. HOWE

THE optical-glass problem, so far as the United States was concerned, can be simply stated. Large quantities of dependable quality were required immediately, the varieties being limited to a half dozen or so necessary for military optical instruments. It should be understood that by optical glass is meant that type of glass which is so made that its physical characteristics may be controlled within rather narrow limits, so that it is suitable for the exacting requirements of photographic lenses, range finders, spotting telescopes, binoculars, periscopes, gun sights, and similar modern warfare requisites.

In order that the complexity and magnitude of this problem may be more clearly understood, it will be well to examine briefly the history of its development elsewhere and understand the condition which prevailed in our country prior to August, 1914.

Prior to 1886 the glass makers were offering a very limited variety of optical glass to the makers of refracting instruments, and the perfection of the various microscopes, telescopes, etc., was necessarily limited to the possibilities presented — a few crown and flint glasses. The possibility had been established of combining two lenses made from the available glasses into a doublet so as to bring pairs of colors to a common focus on the optical axis of the lens, thereby diminishing chromatic aberration. Means to render the image almost entirely free of spherical aberration had also been devised, but no attempts were

made to introduce new glass fluxes, and effort was expended only in perfecting technical manipulation and adding to the list of dense flints.

To this state of affairs there were, however, a few notable exceptions: Fraunhofer, the German optician; Faraday, the great investigator; and Harcourt, an English clergyman. Fraunhofer succeeded in finding glass which showed a diminution of the secondary spectrum, but the new glass was not produced on a commercial basis and the formula was unfortunately completely lost. In 1825 Faraday was appointed by the Royal Society, together with Sir John Herschel and Mr. Dolland, on a committee to examine, and if possible, to improve the manufacture of optical glass. The results of the systematic and very exhaustive experiments were reported minutely by Faraday in 1829, and although glass so found did not prove to be of important practical use, yet the work performed had much directional influence on subsequent researches.

Harcourt could not obtain from his small meltings pieces of sufficient size and perfection to permit a complete spectrometric analysis, and lacking information which could be gained only with the spectrometer, his subsequent work suffered for want of guiding experience. However, these researches were not entirely in vain, since certain facts were established relating to the effect of some chemical elements upon the refraction of light.

Until the late seventies silicon, sodium, potassium, calcium, lead, and oxygen had been the only elements used, excepting perhaps alumina and thallium in an experimental way. Crown and flint glasses were being produced of a far better quality as regards clearness, freedom of color, and homogeneity, and flint of far greater refractive power and dispersion, than had been offered up to this time.

In the late seventies Professor Ernest Abbe of the University of Jena published a paper on the microscope, in which he made an appeal to scientists to take up the improvement of optical glass, and pointed out that scientific instruments were in

a state of arrested development awaiting the perfection of glass which would offer a greater diversity in mean index, and mean dispersion, and render possible a higher degree of achromatism, thus diminishing the secondary spectrum. This plea attracted the attention of Otto Schott, and after communicating with Abbe, the two began an investigation of the problems, and started first of all to determine the chemical-physical principles underlying the making of optical glass. In experimenting with various combinations of elements new to the glass industry, several limitations had to be borne in mind. First, the flux must not act upon the material of the crucible and so absorb impurities. Second, elements which evaporate during the process tend to produce veins and must not be used. Third, cloudiness, crystallization, and bubbles must be avoided in the process of melting, cooling, and subsequent re-heating. Fourth, it must be possible to bring the glass from the plastic to the solid state without producing stress. Fifth, glass must not be tarnishable or hygroscopic. Sixth, it must be colorless and physically strong enough to bear the manipulation necessary in grinding and polishing.

Beside silicic acid, the only glass-making acids were boric acid and phosphoric acid and perhaps arsenic acid. There was a tradition that these acids only gave tarnishable glass, but experiments showed that phosphoric and boric acids could be combined with many metallic oxides and in addition to the six usual elements, namely, silicon, potassium, sodium, lead, calcium, and oxygen, the following were introduced by degrees in quantities of at least 10 per cent: boron, phosphorus, lithium, magnesium, zinc, cadmium, barium, strontium, aluminium, beryllium, iron, manganese, cerium, didymium, erbium, silver, mercury, thallium, bismuth, antimony, arsenic, molybdenum, niobium, tungsten, tin, titanium, uranium, and fluorine.

It was soon seen that by the introduction of new elements the variation of the hitherto fixed relation between refraction and dispersion could be attained. On the other hand, very few of the elements rendered the dispersions of crown and flint

more similar, whereby the shortening of the secondary spectrum could be effected. Boric acid is peculiar in lengthening the red end of the spectrum, relative to the blue, while potassium, and sodium have the opposite effect. In the old glass, flint has a higher index and greater dispersion than crown glass, and lengthens the blue more than the red. Hence it was desirable to introduce into flint glass as large a percentage as possible of boric acid. The work, being empirical, was very tedious, but after a great many trials, in which the problems of suitable crucibles, stirring apparatus, etc., were not inconsiderable, a series of phosphates, borates, and boro-silicates was successfully produced in small quantities.

The question of annealing soon became important, and after a great many trials and subsequent testings with polarized light, the process known as fine annealing was perfected. It was discovered that the temperature of solidification lay between 370° C., and 465° C., and by spreading the fall of 95° over an interval of four weeks or more, perfect results were obtained. This involved the construction of an oven with thermo regulators, whereby the temperature might be kept at any point and allowed to fall with any desired slowness.

Up to 1886 the net result of all these epoch-making discoveries and new processes was nineteen glasses of essentially new optical characteristics, and the researches conducted by Abbe and Schott, with the help of the University and the Prussian Diet, soon made Jena the world's center for the highest grade of optical glass. Through this small but essential component of optical instruments of all kinds, Germany exercised great power over scientific and military progress in optics. The wide-spread use of German scientific instruments needs no emphasis, and it is interesting to note that the best military optics among the armies and navies of the Allies until long after the war began, were made with Jena glass, and only the fact that a large stock of this glass was in America enabled our optical instrument-makers to carry on until American-made optical glass could come to their relief.

It is true that optical glass was also being made in England and France, but those countries needed all the glass they could produce, and as a result, the glass sent here, although for use in instruments being made for their accounts, was not always wholly satisfactory.

That very high-grade optics are essential in modern warfare is at once obvious when we consider improvements in Ordnance. In the days of the Revolution the combatants are said to have waited until they could see the whites of the eyes of their enemies before firing; in the Civil War firing was point-blank; in the Spanish War 6,000 yards was the maximum graduation required on the range-finder. Today the horizon is the limit in the larger instruments, and much progress has already been made with range-finding methods which are necessary for distances beyond the range of observation from the ground.

Now what is the history of optical glass in America? The oldest record states that some fair-grade optical glass was made by the Macbeth-Evans Glass Company in the period between 1890 and 1893, during which time they had the assistance of a Mr. Feil, a French glass-worker who had had experience with Mantois. Both crown and flint were made but there are no details as to the quantity produced, the percentage of usable glass secured, nor the quality. At that time, as later, there was no demand for other than European glass, the cost of development would have been large, and the results quite uncertain. Even if success was attained in producing usable glass, the total volume of the business has never been such as to be attractive, so that the work ceased. The next date is 1903, when Mr. William Bausch, of the Bausch and Lomb Optical Company, conducted a few small-scale experiments, but only with discouraging results. The question remained dormant until 1912, when Mr. Bausch resumed his work and had a small, round, oil-fired furnace constructed. It was soon found, however, that it was impossible to properly control this furnace and in the spring of 1913 the firing was changed over to uncarburetted gas supplied by the local artificial gas company.

Some time previous to this date Victor Martin, a Belgian glass-maker, had come to this country with the hope of starting an optical glass industry in America. He found European glass very strongly entrenched and no producer of optical glass in any way interested in his project, even provided satisfactory glass could be produced. He turned again to the plate-glass industry, but was fortunately attracted by an advertisement placed by Mr. Bausch in the hope of securing an experienced optical glass man to assist him in his work. In the spring of 1912 Mr. Bausch personally engaged Mr. Martin and serious work began. There was some difference of opinion as to whether the considerable expense involved in developing the industry was justified in view of the fact that European sources of supply were so satisfactory and the price of glass, which was from \$1.50 to \$20 per pound, was considered reasonable. Experimental work, therefore, was discontinued during the late autumn of 1913 and was not again taken up until the spring of 1914. Some usable glass was made from 1912 on and in the autumn of 1914 two single pot furnaces of the regenerative type and one pot arch were constructed at Rochester. Small pots were used at first and it was not until May, 1915, that the first melt in a pot, 26 by 26 inches, was made.

The outbreak of the war brought the seriousness of the glass situation to the attention of the Bureau of Standards, and in the winter of 1914-15 experimental furnaces and auxiliary apparatus were installed at the Pittsburgh laboratory, with the intention of starting at the bottom and working out the particular technique peculiar to the making of optical glass. The first 1,000-pound pot was installed in this plant during the winter of 1916. In August, 1914, the Pittsburgh Plate Glass Company began correspondence with the optical instrument makers and in April, 1915, began their preliminary work, strong in the belief that they could develop glass that would meet all the requirements. They passed rapidly through the experimental stages to 10-inch and then 16-inch pots, taking over plate-glass furnaces for the purpose of melting optical

glass and constructing new furnaces designed to give better results. They were encouraged in their work by the Eastman Kodak Company, which placed large orders for suitable glass on a basis which took into consideration a share in the expense of development.

In June, 1915, Keuffel and Esser, finding their supply of glass running low, gave permission to their glass moulder to undertake optical glass making, and, strange to say, this moulder was the same Mr. Feil who had earlier been connected with the Macbeth-Evans Glass Company. He made some useful glass in Hoboken, but by November, 1915, had decided to take up other work and at that time C. W. Keuffel undertook the task along scientific lines. Mr. Keuffel, unaided in his researches, made such progress that by January, 1916, he was able to produce at least one pot of boro-silicate crown from which more than 200 pounds of usable glass was secured. During the following months he was able to make much of the glass required in that plant.

During the summer of 1916 the Spencer Lens Company built a glass furnace in their plant at Buffalo, and with the help of a general glass-maker, started to work. The furnace was found to be unsuited to the work and it was soon seen that other arrangements would have to be made. Consequently, a small plant was built in Hamburg, New York, a suburb of Buffalo, in the spring of 1917, and this was later greatly enlarged. When the United States entered the war, the Macbeth-Evans offered their services to a department of the Government and were about to enter into a contract when it was learned that two other departments of the Government had already made arrangements for optical glass and there seemed to be no further need of their services. The National Optical Glass Company, a subsidiary of the Hazel-Atlas Company, of Washington, Pa., and the Carr-Lowrey Glass Company, of Baltimore, also made some glass, but details of their achievements are lacking.

It should be emphasized that optical glass is not just glass.

The skill required for its successful production is quite properly comparable to that required for exact quantitative analysis. There was no time to look into the many scientific problems encountered. It was the same insistent demand for production, and still more production, but always within the limits as regards quality, which could not be greatly extended even in the war emergency. Good optical glass must be homogeneous, both chemically and physically, it must have definite refractive indices for different wave lengths of light, it must be as free as possible from color, have a high degree of transparency, extreme stability against weather and reagents, and have toughness as well as hardness.

When glass is chemically homogeneous it is free from striae, bubbles, stones, crystals, and cloud. Striae are variously known as veins, cords, threads, and ream by glass-makers. Striae come from a variety of sources and even when the melt is comparatively free from them, lines of flow may be set up by suddenly moving or jarring the pot. These lines of flow may bring in glass from the sides, where it has been affected by the pot, from the bottom, where there may have been selective settling, or from the top where the volatilization may have changed the composition enough to make the extremely small difference in refraction which spells striae. Striae are frequently due to excessive action of the glass upon the pot, insufficient or inadequate stirring, incorrect temperatures, or cooling of the pot in arches, where the heat is so great as to cause the stiff crust on the partly cooled pot to re-melt and start lines of flow by convection. Striae usually show a high percentage of silica and alumina. One of the important remedies is proper stirring and this differs according to the glass and other considerations, such as the selection of a pot built with due regard for the kind of glass which is to be melted in it.

For some uses small striae if in one plane, are of such trifling consequence that the glass can be used for certain types of lenses. This led to the American war-time method of roll-

ing optical glass into thin sheets just as plate glass is made — something quite unheard of previously in optical glass manufacture. Some glass of nearly every variety has been treated by this method, principally in the plant of the Pittsburgh Plate Glass Company, and later elsewhere.

Bubbles, likewise called seeds, air bells, boil, and pot bubbles, are also a source of great annoyance and show lack of chemical homogeneity. They come from many sources and no doubt are entrapped mechanically. Some form during the reaction, cling tenaciously to the sides and bottom of the pot, and loosen but gradually during the stirring. Others doubtless represent dissolved gases, air stirred into the mass, and steam from leaking water-cooled stirring rods, and under unusual circumstances, vacuum bubbles resulting when a pot is cooled very quickly. Among the methods to free the glass of these bubbles, can be mentioned the use of arsenic in quantities not over 0.3 per cent, and of antimony oxide which reacts at a high temperature with the evolution of gas, which rising through the mass, literally sweeps out the small bubbles. The Pittsburgh Plate Glass Company developed the use of ammonium nitrate for this purpose, the compound being introduced in the shape of a small moulded stick. The nitrate is volatilized completely and gives off large bubbles of gas when forced to the bottom of the pot of glass at the high "fining" temperatures. These methods are called "blocking" and sometimes a potato or block of wet wood is forced to the bottom of the pot, the object again being to sweep out the bubbles by the use of larger ones, and this action also tends to mix the glass. However, some glass cannot be entirely freed from bubbles.

Stones refer to fragments of undissolved materials and more often to pieces of the pot wall or the furnace crown which fall into the pot. A good pot will cast very few, sometimes no stones into the melt. Occasionally stones are introduced into the glass during the pressing of the irregular pieces into desired shapes.

Crystallization results from super-saturation, just as in any solution, and when the glass is cooled too rapidly crystals may also be formed even to the extent of devitrification.

At one time each of two manufacturers had much trouble with cloudy glass. It has been shown that this may be due to chlorides or sulphates in the potassium carbonate, or in the case of medium and dense flints, to excessive arsenic. Some observers think the material to be present in colloidal form, for when glass containing selenium, copper, gold, etc., is cooled slowly a high color results, but if cooled quickly, the glass is often clear. Potassium carbonate with 0.1 per cent sulphur trioxide gave good results. When 0.4 per cent. was reached the pot glass was milky at the edges, and when 0.75 per cent. was present, the entire mass was spoiled. The skilful use of high temperatures is said to be a good remedy for this lack of chemical homogeneity.

Physical homogeneity is just as important, for strains cause deformity of optical surfaces, give astigmatism, and may even lead to cracking of lenses. It is out of the question to produce high-grade optical parts with glass not free from strain or internal stress—hence the necessity of fine annealing. The softening point of glass is the temperature at which it flows under its own weight, while the temperature at which it yields slowly under loads approaching in magnitude its crushing strength is its practical annealing temperature. Heretofore annealing has been done by cooling so slowly that there is no large temperature difference between the surface and the center of a pot of glass. This requires expert manipulation and extreme regulation of the temperature fall, as well as exact pyrometric control. Drs. Adams and Williamson of the Geophysical Laboratory arrived at the conclusion that if the pot were held long enough at the high temperature to allow internal stress to be removed by the molecular movement of the glass, yet with the temperature below that at which the glass would flow, annealing could then take place much more rapidly. While under this treatment strains would again be set up, they

would practically disappear when the whole mass again reached the same, that is to say, room temperature. This method of annealing has been found satisfactory for small and ordinary-sized blocks and effects a great saving in time.

It is obvious that with such rigid requirements it becomes necessary to develop adequate methods for testing. The interference figure observed in the black field of a polariscope with crossed prisms is customarily used as an indication of strain. Dr. Wright of the Geophysical Laboratory devised a test based on the assumption that because two rays of different index are formed as a result of the strain, these seriously affect the image formed. The path difference of two such rays is, therefore, a measure of strain and this can be expressed in millionths of a millimeter per centimeter of path traveled. In a well annealed glass this path difference is 5, a fairly good glass 10, and that which is barely usable 20 millionths of a millimeter. In Government inspection the value 10 was ordinarily used, with between 5 and 10 as the standard in special cases.

The refractive index and dispersion are two physical constants of utmost importance and successful glass-making means turning out pots of the same glass within one in the third decimal place in refractive index. Dispersion is of fundamental importance when designing lenses to avoid aberrations, and is expressed as the V value. This is the ratio of the refractive index for the D or sodium line, minus one, to the difference between the refractive indices for the F and C lines.

Uniformity in the constants is very necessary, for of course all grinding and polishing tools cannot be changed with every batch of glass. Lead increases refractive index as well as dispersion, and extends the blue end of the spectrum. Barium raises the index, but does not relatively increase the total dispersion nor extend the blue end of the spectrum to the same extent as does lead. Zinc is intermediate in its effect, while calcium raises slightly both the index and the dispersion without extending the blue. Boron cuts down the total dispersion.

Freedom from color is also a prime consideration and because

of their influence upon light absorption, decolorizers may not be used. Iron, copper, nickel, cobalt, chromic oxide, vanadium, and manganese are to be avoided, both in the batch and in the pot. Transparency is closely related to color in that the use of decolorizers is prohibited, inasmuch as what they frequently do is to form the color complementary to that of the glass, resulting in a gray which is very objectionable. Elements which impart a high color must, of course, be avoided.

Stability, hardness, and toughness are all properties which may be largely controlled by the chemical composition of the batch, the most desirable qualities being obtained in low alkali glasses.

It is apparent, therefore, that the production of good optical glass falls into three or four principal problems, namely, raw materials, good pots, special pots for special batches, temperature control, and glass stirring. From the nature of these problems it is also clear that a good grounding in physics, chemistry, and engineering is much more to be desired than previous glass experience, the pre-war dogma of the Germans to the contrary notwithstanding.

The Pittsburgh laboratory of the Bureau of Standards continued its investigations and did what it could to place the information gained at the disposal of the public. The glass manufacturers patriotically adhered to their determination to make glass, but it was soon found that there were not enough trained scientists actively engaged on the problem. It was late in 1916 that a new group began to become involved. Dr. F. E. Wright was asked to give an opinion on the cause of milkiness and clouds in certain glass, and while he professed no knowledge at the time, he did endeavor to help. Later on the Council of National Defense became interested, principally through members of the Naval Consulting Board, and Dr. Wright went to Rochester to learn if coöperation would be welcome. In April, 1917, under the direction of Dr. A. L. Day, Director of the Geophysical Laboratory of the Carnegie Institution of Washington, the first group from that laboratory went to the plant

of the Bausch and Lomb Optical Company with Dr. Wright in charge. At that time the plant production was about 3,000 pounds net. per month.

At first there was certain passive resistance to be overcome, largely because of the belief in technique and trade secrets, and it became necessary to demonstrate the efficiency of applied and theoretical science. This fortunately Dr. Wright was able to do within two or three weeks by working out the curves for three component systems based on the published analysis of some 110 German glasses. Silica, lead oxide, and alkali oxide are the three components in a flint glass. Too little silica gives a soft glass, too much alkali one that is hygroscopic, and too much lead will cause crystallization. A diagram was eventually worked out so that batches could be computed so accurately in advance that within an experimental melt and one or two large melts, glass of a desired quality could be made.

This marked a most important advance, not only because of the extreme usefulness of such a method, but because it demonstrated to the adherents of secrecy that science could be more potent than technical skill. Thereafter an efficient coöperation was enjoyed between the best that the country afforded in technical skill and scientific knowledge.

The active support of the Geophysical Laboratory group was sought because they were the most experienced in the study of silicates, in working at exact high temperatures, and in methods requiring precision. They began work at the point where the best progress in commercial production had been made, and where the greatest amount of technical skill was available. They were able to add their scientific experience and at the same time acquired the technique of glass-making so rapidly that by June, 1917, they were able to manage the plant in its entirety without difficulty.

The progress at Rochester became so gratifying and the demand for glass so great that the Pittsburgh Plate Glass Company tore down their fence of secrecy in December, 1917, and invited coöperation. The Geophysical Laboratory took charge

and the Bureau of Standards assisted in the inspection of the product. In December, 1917, the Geophysical Laboratory also took entire charge of the plant of the Spencer Lens Company and with a free hand was soon making glass equal to that from Jena.

Assistance of the utmost importance was brought to bear upon the glass problem from other quarters. The Geological Survey put men into the field to find suitable sand, limestone, and clays, and were successful. Sand of high chemical purity and composed of uniformly small grains was secured at Rockwood, Mich.; Hancock, Md.; and Ottawa, Ill. Interesting experiments were conducted on the removal of iron from other sands by the use of chlorine and later phosgene, but this method of treatment proved to be too costly, and in the meantime sand sufficiently free from iron was found. Potassium carbonate of necessary quality was produced by Armour & Company, who deserve credit for the excellent work done on this important raw material. In some glass sodium could be substituted for potassium, but in certain cases the glass is inclined to be less brilliant.

Good sodium carbonate, barium carbonate, boric acid, zinc oxide, arsenic trioxide, and precipitated calcium carbonate were finally secured. Lead oxide with less than 0.02 per cent. iron oxide was also secured and by exercising careful chemical control, no great difficulty was experienced with raw materials.

Pots have been mentioned, but we must emphasize their real importance. Poor pots can cause all manner of trouble, ranging from breaking at critical points and necessitating the rebuilding of a furnace, to dissolving to a detrimental degree in the glass melt. The Pittsburgh Plate Glass Company was already accustomed to making special pots, and in June, 1917, began experiments involving feldspar as an ingredient. While their work was in progress the Bureau of Standards was successful in devising unusually good pots for optical glass. This work was under A. V. Bleining, who also devised a successful method for casting pots. Most of the pots are 36 inches in

diameter and height and hold 1,000 pounds of crown, and 1,500 pounds or more of dense flint. Pots sometimes contribute 0.02 to 0.04 per cent. of iron oxide to the glass, which is very objectionable. Again, if a high refractory clay with poor bonding qualities is mixed with a better bonding clay, the latter may dissolve out, causing stones to be cast into the glass. The purification of pots after building has been attempted, but it makes the pot porous and entirely too fragile. The outcome of Bleining's work was a so-called porcelain type of pot, made up of white ware bisque, crushed to pass a ten-mesh sieve, 35 per cent.; pot shell crushed to pass a ten-mesh sieve, 10 per cent.; feldspar, 3 per cent.; flint, 4 per cent.; Tennessee ball clay, Number 5, 15 per cent.; Illinois bond clay, 5 per cent.; and kaolin, 28 per cent. These pots were made by hand and a typical formula for a cast pot is: whiteware bisque, 48 per cent.; plastic bond clay, 23 per cent.; kaolin, 24 per cent.; feldspar, 5 per cent.

These pots withstand the severe corrosive action of even dense barium crown glass, and are ready for use in much less time than the German type of pot. Just as the glass-makers did all they could to produce a sufficient quantity of good glass, so the pot-makers continued their researches and contributed largely to the final success. La Clede-Christy, the Buckeye, the Gill, and the Willetts Clay Products Companies deserve great credit, while the work on pots is probably considered the greatest contribution of the Bureau of Standards to the glass problem.

In furnace operations the cycle has been shortened from the two and a half days heretofore used customarily to twenty-four hours, a very important improvement in glass-house practice which was worked out by the Geophysical Laboratory in the plant of the Spencer Lens Company. This has been accomplished by improvements in methods of stirring, stirring machines having almost eliminated the hand stirring which Jena had considered indispensable. Proper stirring is perhaps the most difficult part of glass-making technique and involves

a great many interdependent factors. The time of starting and stopping, the temperatures to be held throughout the operation, and the path followed in the stirring are all important. The stirrer must come near enough and yet must not be too close to either side wall or the bottom of the pot.

Simple inspection methods for purposes of rough sorting were evolved, and then more refined methods for use at other points. An immersion method, using liquids of the same refractive index as the glass, served well for locating striae in rough glass chunks, and a combination of this method, the work of the Bureau of Standards, with monochromatic light served to detect the finest striae.

We have referred to annealing and the progress made in that art. The German practice has been to place chunks of glass in square molds, and heat them until the glass would flow into the shape of a plate, in which condition annealing took place. The fall in temperature from 465° C. to 370° C. was spread over an interval of four or more weeks. The American practice is to heat the glass in a muffle to the softening point and then to press it into the desired shape for grinding and polishing. Annealing of these small pieces may then be done in some instances in three days.

As has been pointed out, there is a certain danger in the use of the pot arch as a chamber in which to allow pots of glass to cool. This danger comes from the re-melting of the stiff crust and the skin on the sides of the pot, which form before the pot is placed in the arch. This re-melting starts convection currents which may sweep into the glass, producing striae. At a time when there was a scarcity of pot arches, the Pittsburgh Plate Glass Company tried banking the pots with sand and this experiment led to the use of refractory lined iron drums which might be let down over the pot. This practice has been widely followed and is quite successful.

This same company also worked out the rolling of optical glass into sheets on a casting table, employing technique similar to that in the manufacture of plate glass. The spectacle

glass of the country was made in this fashion during the war and it has become the established procedure for that type of glass. Much optical glass has also been made in this manner. After casting, the glass is passed into lehrs where it stays six hours or more to cool. Grinding and polishing can be done on the large pieces before cutting for inspection.

A large number of batch formulæ have been developed and the production of newer and better types of glass is the subject for continued research. Some of the limitations may be mentioned. If silica is used in quantities above 75 per cent. the glass cannot be properly melted. Alkali must be below 20 per cent. or the glass is hygroscopic. Lime must be less than 13 per cent. or crystallization will result. Lead above 70 per cent. also will cause crystallization. Barium oxide may be used up to 50 per cent., but great care must be exercised or the pot will be attacked. Boron oxide may be used up to 15 per cent. or 20 per cent., but zinc above 12 per cent. causes crystallization. Alumina above 5 per cent. gives a glass that is too viscous, but alumina toughens glass and serves to counteract the tendency to crystallize. Arsenic increases transparency by setting up an oxidizing action at the high temperature of the furnace, thus reducing the color which arises from the presence of iron. Nitrates alone are too active. Carbonates alone do not give the necessary oxidizing agents, while if too much alkali is used with too little nitrate, the glass will not "fine" well.

From importing exclusively in 1914, the United States rapidly developed the industry until late in the war we were in position to become exporters and served Italy's requirements during the last months, taking a considerable burden off the shoulders of the English and French makers. Of the 675,000 pounds of ordinary crown, boro-silicate crown, barium crown, ordinary hard crown, light flint, medium flint, and dense flint produced for war purposes, 95 per cent. was made under the direction of the Geophysical Laboratory, with ten men in the field and thirteen at work concurrently in the laboratory. About 2.8

per cent. was produced at the Bureau of Standards which was rapidly approaching its schedule of two tons per month when the armistice was signed. Keuffel and Esser made glass for their own use. At the close of the war the maximum capacity of the Bausch and Lomb Optical Company plant was above 50,000 pounds per month, the Pittsburgh Plate Glass Company, 40,000 pounds, and the Spencer Lens Company more than 15,000 pounds. The optical companies will continue production and development work with the object of making the best glass in the world for their own use and for others. Some scale of the operation can be conveyed by the statement that in the Bausch and Lomb Optical Company plant 33 million cubic feet of gas were required monthly.

Another achievement has been the percentage of glass found usable. All German reports place 20 per cent. as a maximum and state that from 15 to 18 per cent. is more nearly the average. The record shows that toward the end of the war, an average of $23\frac{1}{4}$ per cent. of all optical glass produced at one of our large plants was usable. Transmission now equals that of the Jena glass, as does the absorption, which has been reduced 0.5 per cent. per centimeter of glass.

To record thus briefly the contributions of certain scientists and manufacturers for the winning of the war seems inadequate in view of the tremendous obstacles which had to be overcome under unusual pressure. Increased production meant much more than merely the multiplication of manufacturing units, and to have accomplished all that was done is only equaled by certain other scientific work where, as in this case, it was necessary in a few months to cover the ground that had been covered elsewhere during a period of years.

THE RÔLE OF CHEMISTRY
IN THE WAR



VIII

THE SUPPLY OF NITROGEN PRODUCTS FOR THE MANUFACTURE OF EXPLOSIVES

ARTHUR A. NOYES

AN adequate supply of nitrogen compounds, particularly of nitric acid and ammonia, was of vital importance in ensuring victory in the war. From nitric acid are made all the important explosives, smokeless powder, picric acid, trinitro-toluol, ordinary black powder, dynamite, and ammonium nitrate. The last of these materials, the simplest of them all, came during the war into the greatest prominence as one of the most important explosives. In fact, one of the leading munition authorities of England declared that the war could be won only with ammonium nitrate, as no other explosive could be produced in quantity adequate to meet the enormous demands of the Allied armies. This development of the use of ammonium nitrate brought about a heavy demand for ammonia; so that while in the early stages of the war our chief concern was an adequate supply of nitric acid, we soon became no less interested in a sufficient and ample production of ammonia.

Of these two nitrogen compounds there are only three important sources.

The first source is Chile saltpeter, or sodium nitrate, which is found in a natural state in the dry regions of Chile, and which until recently furnished the total supply of nitric acid of the world. We depended for our own nitric acid supply at the beginning of the war wholly upon the Chilean imports.

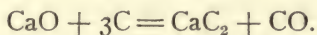
This was, however, a precarious source of supply. For in the first place, it required ships for its transportation, and ships were scarce. In the second place, there was always danger that enemy machinations, through the purchase of the Chilean mines, destroying the plants, or blowing up the oil supply used for fuel, would reduce the production; or that our supply might be cut off entirely, by the establishment of a hostile submarine base on the Pacific Coast. All of these possibilities made it unsafe to rely for our nitric acid supply on Chile salt-peter alone. But, even if none of them actually came about, it would still be impracticable to get in this way the huge amount of nitric acid that would be needed by the American Army.

The second source of nitrogen products is the ammonia produced as a by-product in the manufacture of gas and coke. There has been developed, as will be described later, a process for the conversion of ammonia into nitric acid, so that if we could get, from any source, an adequate supply of ammonia, it could be converted into nitric acid. But unfortunately, this country was still producing most of its coke in the so-called "beehive" oven, which is simply a hemispherical kiln, into which the coal is charged and set on fire; the products of the combustion being allowed to pass into the air, whereby the ammonia and valuable hydrocarbons that might be obtained are lost. It is true that during the preceding decade there had been a rapid introduction of the so-called "by-product" ovens, in which the coal is heated in closed retorts, and the gases are passed through condensers and scrubbers by which the hydrocarbons and the ammonia are recovered. It was even claimed before the war by representatives of the by-product industry that this rapidly increasing supply of ammonia would alone suffice to meet the military needs of the Government; but the result proved that it was utterly inadequate. The production by this process is necessarily limited by the fact that the by-product industry is dependent upon the steel industry; for it is mainly in the metallurgy of steel that coke finds its use,

and ammonia can be produced at reasonable cost only in proportion as there is a demand for coke.

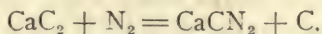
The third source of these nitrogen compounds is atmospheric nitrogen. During the last fifteen years there have been developed a number of chemical processes by which the nitrogen of the air is "fixed," as we say, whereby ammonia, nitric acid, or cyanide is produced. Only the three fixation processes which had been operated before the war on a commercial scale will be here briefly described. These are the cyanamide process, the synthetic ammonia process, and the arc process.

1. The cyanamide process starts with lime and powdered coke. The first chemical reaction that takes place results in the formation of calcium carbide (CaC_2), as follows:



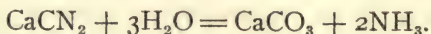
This is the substance which is used so extensively in the manufacture of acetylene for use as an illuminant and in oxy-acetylene welding. The carbon monoxide escapes as a gas. The first step in the cyanamide process is carried out in huge electric furnaces. The charge of lime and coke in small lumps is fed down through the furnace, in the center of which stands a large carbon electrode; the walls of the furnace form the other electrode. The mixture is heated to a very high temperature, and the melted carbide is tapped off at the bottom from time to time, and allowed to solidify.

The carbide is then crushed and subjected to the nitrifying process. It is packed into large basket-shaped containers three to six feet high and two to three feet in diameter. These baskets, which are perforated with small holes, are enclosed in an iron vessel into which is forced nitrogen made by distilling liquefied air. The chemical reaction is started by heat produced by passing an electric current through a resistance wire, placed in the axis of the basket. The reaction which takes place is as follows:



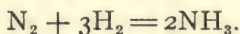
This gives us a product, CaCN_2 , called "cyanamide," which contains some unchanged carbide and some lime and graphite.

For the production of ammonia the cyanamide is next treated with steam, whereupon the following reaction takes place:



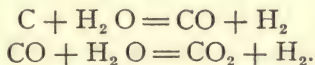
This process is carried out in huge autoclaves about 20 or 30 feet high and 5 to 6 feet in diameter. The powdered cyanamide is fed into an alkaline solution, and then steam is blown in; the mass heats up, the reaction begins and becomes violent, and the ammonia is liberated. After it has attained a pressure of 12 to 15 atmospheres, it is blown off into gas-holders. After the reaction has spent itself, the residue is again charged with steam so as to get a complete removal of the ammonia. When carried out properly, it is practicable to get substantially all of the nitrogen in the form of ammonia.

2. The synthetic ammonia process is an extremely simple one chemically, involving the following reaction:



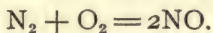
There is an interesting history connected with the development of this process. The proportion of ammonia which forms from the elements (hydrogen and nitrogen) at atmospheric pressure was known to be extremely small at temperatures where the rate of combination was reasonably rapid; thus it is only 0.13 per cent. at 500° , and still less, only 0.02 per cent., at 700° centigrade. The facts that the *equilibrium conditions* become less favorable as the temperature rises, and that on the other hand a high temperature seemed necessary in order to give a rapid *rate of reaction* led to the belief that there was little hope of basing a technical process upon this chemical reaction. However, a German chemist, Prof. Haber, guided by theoretical considerations which show that the proportion of ammonia formed must greatly increase with increasing

pressure (becoming, for example, 18 per cent. at 200 atmospheres at 500°), undertook elaborate investigations, supported financially by one of the large chemical companies of Germany, first, to develop large scale apparatus which would withstand these high pressures, and secondly, to discover a contact-agent or catalyst which would cause the hydrogen and nitrogen to combine rapidly at a fairly low temperature. After years of research and the expenditure of two or three millions of dollars, the difficulties were largely overcome, and a practical commercial process was developed. The hydrogen required in this process is one of the chief factors in the cost of production of the ammonia. It was manufactured by injecting steam into a furnace containing red-hot coke, mixing the gases so produced with a large excess of steam, passing them over a contact-agent whereby the carbon monoxide (CO) present is converted into carbon dioxide (CO_2), and removing the latter from the gases by scrubbing them with cold water at a pressure of 30-50 atmospheres. The chemical changes involved are expressed by the equations



The nitrogen required in the process was obtained by the distillation of liquefied air.

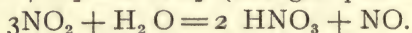
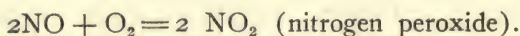
3. The arc process like the synthetic process, involves an extremely simple chemical reaction; namely,



At a very high temperature the nitrogen and oxygen of the atmosphere can, as expressed by this equation, be made to unite to form nitric oxide. In this case the effect of temperature on the equilibrium is exactly the opposite of its effect on the ammonia equilibrium. The higher the temperature, the more nitric oxide is obtained; but there is very little produced

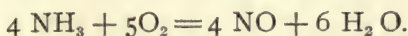
until the temperature becomes very high. At 1600° Centigrade 0.4 per cent. (by volume) of a mixture of equal parts of nitrogen and oxygen is converted into nitric oxide; at 1900° 1.0 per cent.; and at 2400° , 2.2 per cent. It is clear, then, that we can get a considerable production of nitric oxide only by operating at a high temperature. But not only is it necessary to do this, but the gases must be cooled so quickly that in the process of cooling the reaction does not reverse itself, with decomposition of the nitric oxide into oxygen and nitrogen. The only really practical way in which these conditions can be realized is by passing through air a powerful electric discharge. An electric arc produces locally an extremely high temperature, and the gas can be drawn rapidly away from the arc and quickly cooled.

The nitric oxide in the gases coming from the arc must now be converted into nitric acid (HNO_3). This is done by causing the two chemical changes expressed by the following equations to take place successively:



This first chemical reaction takes place of itself when the gas cools to below 150° ; but time must be allowed for its completion, which is accomplished by passing the nitrous gases through a large empty chamber. The second reaction is then brought about by passing the cool gases through a series of high granite towers, often sixty feet high and sixteen to twenty feet in diameter, filled with quartz pebbles over which water is trickling. As this second reaction reconverts one third of the nitrogen into nitric oxide, and the first reaction must again take place before the nitrous vapors can be absorbed by the water, the process is a slow one, and an elaborate absorption system is required. From the towers flows a dilute (30 per cent.) nitric acid, which can be concentrated by well-known processes to the strength needed for the manufacture of explosives.

4. In this connection there should be briefly described the process referred to above for the conversion of ammonia into nitric acid. This consists in passing a mixture of air with about ten per cent. of ammonia gas over red-hot platinum gauze, whereby 90 per cent or more of the ammonia is converted into nitric oxide, in accordance with the equation



The gases are then cooled and passed through absorption towers, whereby the nitric oxide is converted into dilute nitric acid through the occurrence of the chemical changes described in the preceding paragraph.

From a technical standpoint, this was the "state of the art" just before the war; but the commercial development of the various processes had been limited, and there were many difficulties in their rapid installation in this country. To appreciate this, let us briefly review the industrial status of nitrogen fixation at that time, and the economic factors involved in the different processes.

The cyanamide process requires as raw materials mainly pure limestone, coke, and nitrogen (obtainable from liquid air). The synthetic process depends primarily on cheap coal, but it demands elaborate machinery and highly skilled labor. The arc process makes its product directly from ordinary air, but it requires for its economic operation cheap and abundant water-power. As the power requirement was a vital factor in this country, the following quantitative statement in regard to it is of interest. For the fixation of one ton of nitrogen about 10.5 horse-power years are used in the arc process; 2.2 in the cyanamide process, and 0.5 or less in the synthetic ammonia process.

The arc process was being operated on a large scale in Norway, where the water-power needed in great quantity for this process is available at very low cost. It had been introduced also in other countries, but only in a small way. The cyana-

mide process had been installed in all the larger countries of continental Europe, and in Canada and Japan. The synthetic process had been developed exclusively in Germany, and during the war it was being greatly extended there. Had it not been for this process, assuring a supply of explosives, Germany would never have ventured to declare war on Europe.

On this continent the only considerable installation of fixation processes was that of the American Cyanamid Company at Niagara Falls, Canada. This plant had in 1916 a capacity for producing annually 12,800 tons of nitrogen in the form of cyanamide. A small arc-process plant having an annual capacity of about 300 tons had been installed and operated at Nitrolee, South Carolina. The DuPont Powder Company had also made complete designs for the installation of an arc process plant of the Norwegian type.

The detailed information and experience needed for the installation of a cyanamide or an arc process plant in this country was therefore available, being in the possession of some of our leading industrial companies. But this was not true to anything like the same degree of the synthetic ammonia process, the details of which had been kept by the Germans a carefully guarded secret. The General Chemical Company of this country had, however, been working for years on a modified form of the German process; and soon after the declaration of war by the United States this Company placed its information and experience at the disposal of the Government.

This then was the situation in April, 1917, when the Government was faced with the urgent problem of enormously increasing our supply of nitrogen products. It remains to describe the steps that were taken to solve it.

During the year preceding our entrance into the war some preparation had fortunately been made. Congress had passed on June 3, 1916 an act placing \$20,000,000 at the disposal of the President for the erection of nitrogen-fixation plants and

the development of water-power for that purpose. The National Academy of Sciences had in April of that year offered its services in scientific matters; and a little later the Secretary of War requested the Academy to appoint a committee to advise him as to "the best method to be followed in the manufacture of nitric acid by a process not involving dependence upon a foreign source of supply." A committee was formed consisting of leading chemists and engineers; and this committee rendered on June 2, 1916 a preliminary report urging that in view of the unavoidable delays in the construction of adequate fixation-plants, a large supply of Chile saltpeter be imported as rapidly as possible and stored against an emergency; and that efforts be made to stimulate the introduction of by-product coke ovens for the production of ammonia and hydrocarbons. The committee then proceeded to make an exhaustive study of the different problems of nitrogen-fixation under American conditions, and in January, 1917, rendered to the Secretary a full report. In this report the previous recommendations were renewed; and in addition the immediate construction of a plant for the oxidation of coke-oven ammonia to nitric acid and of a cyanamide-process plant for the fixation of nitrogen was recommended, the latter plant to be operated temporarily with newly developed steam power or with existing power purchased from private companies. The cyanamide process was recommended; for it was evident that sufficient power could not be secured for the operation of a large arc-process plant, and no information was available that would make possible the proper construction and operation of the German synthetic process. In the meantime the Chief Chemist of the Bureau of Mines had been sent abroad by the War Department to study foreign developments of nitrogen-fixation, on which he presented a report in January, 1917.

This Academy Committee was later replaced by the official Nitrate Commission of the War Department with a personnel that included several members of the original committee and a number of prominent government representatives; and the

Commission acted in an advisory capacity to the Secretary throughout the war.

During the summer of 1917 a Nitrate Division was organized in the Ordnance Department; and contracts were made for the construction of two fixation-plants. The first one of these arranged for was a synthetic-process plant to be built at Sheffield, Alabama, by the Government with the coöperation of the General Chemical Company, employing the recently disclosed process of that company. It was to have a capacity of 20,000 tons of ammonium nitrate a year. This plant was constructed during the following year; and one of the three units was completed before the armistice was signed. Its continuous operation was, however, prevented by difficulties which had not then been overcome.

The second fixation plant was built at Muscle Shoals, Alabama, for the government by the American Cyanamid Company. It is the largest, and doubtless the most perfect, cyanamide-process plant ever constructed. It is designed for the production of ammonium nitrate, and has a capacity, of 110,000 tons of that material per year. It was already partly in operation at the time of the armistice, but has since been shut down, pending decision as to the practicability of manufacturing nitrogen-products for fertilizer use upon a paying basis.

As the American Army grew in size, with still larger increases in prospect, the need of ammonium nitrate became still more pressing; and the construction of two new cyanamide-process plants, each with a capacity of 55,000 tons of ammonium nitrate per year, was begun in the summer of 1918. These were located near Toledo and near Cincinnati, Ohio, where surplus municipal power was available. The construction was suspended, and the structures were salvaged when the armistice was declared.

As in many other fields involving the applications of science, the war demands have given a great stimulus to the develop-

ment of the art of nitrogen fixation,—an art which, by furnishing cheaper fertilizer and thereby increasing the crop-production of the world, is bound to contribute greatly to the welfare of mankind. From the beginning of the war, the governments of England, France, and the United States, as well as many of the large chemical companies of those countries, actively prosecuted investigation in this field. When the Nitrate Division of our Ordnance Department was formed, it established a Research Section, and this actively assisted industrial companies and inventors in the development of their processes. And, in coöperation with the Nitrate Investigations Committee of the National Research Council, it initiated and prosecuted researches of its own, in its laboratories at the Nitrate Plant at Sheffield, in those of the bureau of Chemistry and Bureau of Soils at Arlington, and at the Geophysical Laboratory of the Carnegie Institution, which during the latter period of the war liberally placed its facilities and assigned some of its staff to this work.

It is a subject for congratulation that provision has been made by the Government for the continuation of researches upon nitrogen fixation under most favorable conditions. The excellent laboratories at the American University previously used by the Chemical Warfare Service are now utilized for this purpose, funds enough to enable the work to be effectively prosecuted for some time are available, and the investigations are under the competent direction of some of our best research chemists, who will attack the difficult problems involved in a fundamental way.

In conclusion, the hope may be expressed that this brief story of nitrogen fixation in its war relations may contribute to the purposes of this volume by showing the vital dependence of military operations upon the applications of science, and the reactions of war experiences on the development of science itself.

IX

THE PRODUCTION OF EXPLOSIVES

CHARLES E. MUNROE

SINCE the introduction of gunpowder into use it has been quite generally recognized that explosives are essential in the carrying on of war, and it is expected that large quantities of them will be consumed in warfare. It is not as generally recognized that explosives are equally essential for use in industry and that the demands of our modern civilization for coal and many of the ores, and for the carrying out of engineering and a variety of other operations, cannot be met except through the use of enormous quantities of these reservoirs of concentrated energy. An inspection of our census statistics will show a constantly increasing production of explosives until 1909, when there were manufactured in the United States 244,622 tons of explosives in one year, of which less than one-half of one per cent. were designated for military uses. It is believed that the annual production in subsequent years, except that of 1914, was greater than the above but no U. S. Census statistics have been taken except those for 1914 when production of all kinds was lessened during the last six months. (All civilized countries have been engaged in the manufacture of explosives, though none upon so extensive a scale as the United States, during the last half century.)

For several hundred years after its introduction men depended upon potassium nitrate gunpowder alone to perform all the variety of duties demanded of explosives in peace or in war, and it early became the subject of scientific investigation and supervision; Tartaglia, Galileo, Newton, Huygens, and

many other mathematicians and physicists discussed its effects on projectiles; granulation was introduced in 1445; Benvenuto Cellini observed the necessity for adapting the grains to the gun, and devised the system of blending; Hawksbee, in 1702, measured the volume of gas resulting from a known volume of powder; Robins, and then Hutton, developed the ballistic pendulum; and Rumford measured the pressure produced by gunpowder in burning, all prior to the nineteenth century.

In connection with his duties in the office of the *fermier général* of France, Lavoisier was, in 1775, designated *registreur des poudres*, when he at once proceeded to install a laboratory at the Arsenal in Paris and to apply his chemical knowledge to improvements in the production of saltpeter and in the manufacture of gunpowder. Among his pupils was E. I. du Pont de Nemours, who spent some time in the royal powder mills at Essone, qualifying as a successor to Lavoisier as superintendent and who, on July 19, 1802, on the advice of Thomas Jefferson, began the gunpowder works on the Brandywine at Wilmington, Delaware, which have been continued to the present day.

The creation of this laboratory by Lavoisier may properly be taken as the beginning of precise chemical investigations of explosives, and his example was followed by many other chemists, among those investigating gunpowder being Berthollet, Gay Lussac, Violette, Chevreul, Bunsen and Schischkoff, Linck, Károlyi, Noble and Abel, Hare and Debus.

Although picric acid had then been known and, to some extent, used as a bitter principle and coloring matter, and with metal-amines, styled fulminating silver, gold and the like, had been developed as interesting chemical material, the beginning of modern explosives dates from the discovery of mercury fulminate by Howard in 1800, and from the middle of the nineteenth century on followed the discovery of the nitric esters from starch, wood, cotton, glycerin, sugars and other alcohols, known as nitro starch, nitro lignin, nitro cellulose, nitro glycerin, and nitro sucrose; of diazo-bodies, and of hydronitrides;

while the usefulness of the nitro substitution compounds, both those derived from aliphatic hydrocarbons as well as those from aromatic hydrocarbons, and from many of their derivatives as explosives *per se* was established. In fact Sprengel in 1873 stated that picric acid, a nitrosubstitution compound discovered by Woulff in 1771, contains a sufficient amount of available oxygen to render it, without the help of foreign oxidizers, a powerful explosive when fired with a detonator. As each of the parent substances of these organic explosives was known to be a member of a series yielding similar derivatives, most of which through progressive substitution and isomerism would each yield several nitric esters or nitrosubstitution compounds, the number of actually known explosive compounds was very large, while they were greatly exceeded in number by those whose existence had been made evident but which had not, for obvious reasons, such as their scarcity, cost, presence of objectionable radicals, such as the haloids, been developed and made use of. In addition many of these explosive compounds were made use of as components of explosive mixtures, as nitroglycerin was in a multitude of dynamites, or they were modified physically, as nitrocellulose was when by colloidization and induration of its grains it was converted into smokeless powder. Other oxidizing agents were also substituted for potassium nitrate, such as other nitrates, chlorates, perchlorates, permanganates, dichromates, and liquid oxygen, and other combustible agents for the charcoal, such as aluminum, magnesium, hydrocarbons and cereals of various kinds.

In 1870, as a consequence of the Franco-Prussian War, there was formed a Scientific Committee for the Defense of Paris, of which Berthelot was a member. He then directed and conducted researches in explosives, which resulted in the accumulation of the mass of information regarding these substances which is set forth in his "Force des matières explosive," and in the creation, in 1878, of the permanent Commission on Explosive Substances, with Berthelot as Chairman, which has been intensively engaged in researches in explosives ever since.

Similar research organizations were created in other countries. In 1875, "Her Majesty's Inspectors of Explosives" was organized to supervise the manufacture, transportation and use of explosives, with Dr. Dupré as its chemist, and other countries have, with modifications, created similar organizations. In 1877 a French Commission was designated to investigate explosives for use in coal mines and similar commissions have been established in England, Belgium, Germany, Austria, Russia and this country. The United States Bureau of Mines has at its Testing Station in Pittsburgh a most complete equipment for chemical and physical tests of explosives and a force of experienced and capable chemists and engineers. Because of the military importance, testing stations or proving grounds have for a long time been an active part of the army and naval establishments of many countries, together with explosives research laboratories, like those at Waltham Abbey and Neubabelsberg. In this country there have been for a long time such chemical laboratories at Frankford and Picatinny Arsenals for the army, and at Indian Head and Newport for the navy; the United States Naval Torpedo Station Laboratory having been started in 1870 with W. N. Hill as chief chemist. Scientific supervision, accompanied by research, has in recent years characterized the explosives industry. This is universally recognized for those factories in which dyestuffs, photographic and pharmaceutical chemicals are produced and in which explosives, such as the nitro substitution compounds, appear as subsidiary products or intermediates. It has been the case, though to a less extent, in those factories in which explosives are the principal product. Thus, following the special inquiry at the chemical census of the United States in 1900, it was found that the explosives industry employed research chemists and engineers to a larger extent than any other of the chemical industries. Moreover, explosives have for more than a century furnished attractive subjects for research by university professors and advanced students. As a result of all this research activity the literature on explosives is very extensive.

At the outbreak of the war in 1914, explosives occupied an almost unique position among the materials which became of military importance for an enormous number of them were known, a large number of them had been manufactured and used so that the methods of manufacture and use had been commercially developed. Because of this, and the fact that for more than a century they had been the subject of numerous scientific investigations, their characteristics were pretty well ascertained. Since the war was evidently to be of great magnitude and prolonged, the problem with regard to explosives was the selection from among the many known of those which, while offering a large measure of safety to the manufacturer and user, would prove the most effective against the enemy, and could be rapidly manufactured and delivered. As a result, TNT and picric acid were the chief explosives used as bursting agents, and smokeless powder, either single base (nitro cellulose only), or double base (nitro cellulose-nitroglycerin) as the propellents, with mercury fulminate and chlorate mixtures as initiating agents and tetryl or tetranitroaniline as boosters. Black gunpowder played a subsidiary part as used in trench mortars and pyrotechnic devices, while cheddites, ammonals, nitrostarch compositions and similar explosives were used in hand grenades and bombs. Guncotton, which would have been more efficiently used in propellents, was employed to some extent in defense mines and limited quantities of explosives such as ecrastic, schneiderite or explosive D were used because of a special penchant of certain services.

In view of this there should be nothing surprising in the statement that the explosives art and industry was in such a condition of development and preparedness at the outbreak of "The World War for Civilization" that no new explosive compound nor any new principle in application appears to have been evolved or made use of during this war. It is true that the enemy, to piece out its requirements, made use of hexanitrodiphenylamine (long used as a dye under such names as Aurantia, Kaiser Yellow and others) and of hexanitrodi-

phenylsulphide, and both sides employed in drop bombs the liquid nitrogen peroxide explosives indicated by Berthelot in 1881 and well developed by Turpin about that time and styled by him ponclastites. Also chlorinated nitrosubstitution compounds, which had been rejected before the war because of the poisonous nature of their explosion products, were tested out but not adopted for use.

A multitude of explosive mixtures were proposed and some of them were used. The only new one which attained marked prominence and large use was amatol, which was a mixture of TNT with ammonium nitrate. By its aid the enormous demand for bursting charges was met. Its production, however, involved no new idea, for joveite was a similar mixture of nitrosubstitution compounds and ammonium nitrate. Joveite was the explosive which was tested at the Indian Head Proving Ground under Captain Sampson in 1897 and which Admiral Sampson sought in vain for loading the shells of his fleet prior to its encounter with Cervera's fleet. It may be recalled that in the Indian Head tests Commander Couden fired armor piercing shell charged with 8.25 pounds of joveite through 14.5 inches of the harveyized armor of the U. S. S. *Kentucky* and that the shell exploded after complete perforation of the armor. This was the first time in history that such a result was attained and it demonstrated the practicability and efficiency of these nitrosubstitution compound-metallic nitrate mixtures for shell charges.

The real problems that had to be solved after the explosives to be used had been selected were those pertaining to large scale production at high speed and the obtaining of sufficient supplies of raw material. These materials were mainly cotton and glycerine for smokeless powder, phenol for picric acid, toluene for TNT, nitric and sulphuric acids with which to nitrate each of the foregoing, ammonium nitrate, alcohol and mercury; but many other substances playing subordinate parts, as purifying or stabilizing agents and the like, though used in much less quantities than the foregoing, were nevertheless called for

in larger amounts and to be delivered at more rapid rates than had ever been known or even, probably, dreamed of. And this was to be accomplished in this country in the face of interrupted transportation which cut off supplies of niter, sulphur and pyrites; of a greatly increased demand for cotton for clothing, tents, airships, automobile covers, and a variety of other uses; and of the long continued policy of Germany in preventing the manufacture in other countries of many of the chemicals essential in the preparation of explosives, so that all such manufactures had to be developed here *ab initio*.

With the increasing shortage of cotton attention was turned to wood as a source of cellulose. It was known that the earliest and long used smokeless sporting powders, such as the Schultze, were made from nitrated wood and that wood contains considerable proportions of cellulose, but that it was intimately mixed with other bodies which interfered with its use in the production of military powders from it. However, under pressure, methods of large scale purification of the wood cellulose were worked out by chemists on both sides and satisfactory powder produced from it. It is claimed that it was owing to this development and to that of methods for the production of nitric acid from the air that Germany was enabled to continue military operations so long. It was proposed in this country to combine this development of the use of wood pulp with the reclaiming of cut-over turpentine lands; the stumps of the long-leaf pine were to be first treated to obtain from them their spirits of turpentine and resin contents and the residual wood to be converted to cellulose pulp, while the land thus cleared was to be devoted to agriculture or reforestation.

Glycerin is obtained as a side product from fats and oils in such processes as soap-making. For some years before the war there was a constantly growing world shortage which became acute as the war developed. In looking for other sources of glycerin it was recalled that glycerin is always produced to a slight extent in the ordinary fermentation of sugar to alcohol, and this led to a search for and cultivation of the glycerin

producing organism, the preparation of that medium, and determination of those conditions best suited to its growth. The Division of Chemistry, Bureau of Internal Revenue, U. S. Treasury Department, met with success in the employment of *S. Ellipsoideus*, var. *Steinberg* in alkaline sugar solutions under definite conditions of concentration and temperature. Yields of 20 to 25 per cent. of glycerin on the original sugar content were obtained and inedible materials such as Porto Rican "black strap" molasses were found to be the most effective of sugar-containing materials for this use.

Phenol, commonly called carbolic acid, benzene and toluene are produced, with gas, coke and other substances in the dry distillation of soft coal and were originally largely recovered commercially from the lighter coal tar distillates, but, though the coal gas industry was established in this country in 1816, the water gas industry in 1865, and the by-product coke industry in 1892, the proper chemical utilization of the by-products was prevented by the adroit commercial practices of the German manufacturers and merchants, so that in 1914 we practically lacked these industries. It is true that for some years we had employed by-product coke ovens about steel works, where the richer gas was used for heating purposes in hot-blast stoves, soaking pits and the like, and about cities, where the richer gas was sold, either alone or mixed with other gas, such as water gas, as illuminating gas. Also, to meet a constantly increasing demand for higher candle power it had become the practice to strip the gas at the steel works of its benzene and toluene, by oil stripping, and to ship these hydrocarbons to the gas plants for use in enriching the illuminating gas. Furthermore, it had been early recognized that toluene and benzene were formed in the carburetters of water gas plants through the cracking of the petroleum oils used to supply the illuminants to the gas, and between 1900 and 1905 the United Gas Improvement Co. had developed methods for their recovery. None of these operations were, however, conducted on a large scale, so that when this enormous demand came in

1914 and the succeeding years it became necessary to erect production and recovery plants on a scale before unknown, while cracking processes, such as the Rittman, were worked out to secure large yields of these hydro carbons from petroleum. The story is told in detail in Technologic Paper of the Bureau of Standards, No. 117, entitled "Toluol Recovery," while the system of tests applied which contributed largely to the success of these operations is described in Ordnance Department, U. S. A. Bulletin No. 1800, entitled "Methods for Testing to be used in Toluol Plant Operation."

The phenol problem was more difficult since securing the proper coal tars in quantity and the separation and purification of the phenol fraction was too time consuming, and moreover conflicted too seriously with the interdependent industries to be available to any material extent in this emergency. However, benzene was attainable by the means described above and it was known that phenol had been produced from it by first converting the benzene into the potassium benzene sulphonate and then fusing this with potash. As unfortunately potassium compounds were also under the control of the Germans, the use of sodium compounds was resorted to, and, despite the fact that previous attempts to use sodium compounds had failed, a careful study of conditions resulted in this process being made commercially successful. At the same time other methods for the production of picric acid from benzene, based on the latter being first converted into chlor-benzene, were put into successful operation, whereby much of the synthetic phenol was released for disinfection purposes and other necessary uses.

The story of how the nitric acid problem was solved is told by Dr. A. A. Noyes in another chapter. As for sulphuric acid, this country was before the war a leading producer, if not the leader, in this fundamental chemical industry, for by 1914, we were producing annually over 4,000,000 tons of the various grades reduced to 50°B. Extensive plants had been erected with which to collect and convert the enormous quantities of sulphur fumes given off in smelting copper ores. It is true

that many of our acid works had been roasting foreign pyrites but thanks to the inventions of Frasch large deposits of sulphur in Louisiana and Texas had become available, while extensive beds of pyrrhotite in Virginia and of pyrites were drawn upon. Through these means and by limiting the supplies for use in the fertilizer and other industries, in which sulphuric acid had been largely used, the enormous demands of the explosives industry were met.

Ammonium nitrate has a special interest in that not only has it been extensively used as an oxidizing component of explosive mixtures but that unlike the potassium and sodium nitrates, for which it was substituted, it is explosive *per se*. This was indicated by Berthelot in his study of the several different methods of decomposition which ammonium nitrate can undergo when heated. Its use as a component of explosive dopes in dynamite began about 1870 with the introduction of the practice of recovering spent nitroglycerin acids. It was found that the weak nitric acid produced could be most easily and economically reclaimed by neutralizing it with ammonia, and its use in dynamites was largely established through the invention of "protected nitrate ammonia," by R. S. Penniman (U. S. Patent 448361 of March 17, 1891) whereby its deliquescent tendency was overcome. Since then these ammonia dynamites have assumed an ever increasing importance, while ammonium nitrate has been made a component of many other explosive mixtures such as Favier's explosive, ammonal and others which contained no nitroglycerin.

This demonstrated efficiency of ammonium nitrate and its suitability for use in large scale operations created a demand for it in this war which exceeded the capacities of all the previous sources of supply. Ammonium sulphate, produced at gas works and by-product coke works for use as a fertilizer, was available in large quantities and sodium nitrate could with effort be imported from Chile. It was known that during the Crimean War (1854-55) to meet the increased demand for salt-peter for the gunpowder then used, a process was developed

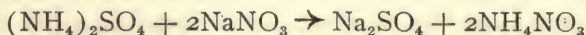
in Germany wherein the potassium carbonate, from beet root residues, was made to react in aqueous solution with Chile saltpeter as follows:



thus not only supplying the desired potassium nitrate but also greatly fostering the beet root sugar industry that Germany was then seeking to promote. It was also known that about this time there was discovered in the sinking of a shaft at the Stassfurt salt mines the so-called *abraumsalze* containing quantities of sylvite or mineral potassium chloride and that at the opening of the Civil War in the United States there was developed a method of producing saltpeter by metathesis of potassium chloride and sodium nitrate in aqueous solution as follows



With these and many other precedents existing it appeared a simple matter to produce ammonium nitrate from the metathesis of ammonium sulphate and sodium nitrate in aqueous solution as follows:



Owing, however, to the possible formation of three different phases of sodium sulphate, five enantiotropic phases of ammonium nitrate, and four different double salts with differing solubilities, the problem was a most complex and intricate one and many who sought to solve it failed. It was solved by Freeth and Cocksedge through a careful quantitative study of the solubility relations and the regulation of the temperature within narrow limits as a result of the information obtained from these data, and their discoveries were protected by English Patent 16,454 of 1910. The method was commercially developed during the war at the plant of Brunner-Mond in Eng-

land and it constituted one of the most notable achievements in physical chemistry as applied to explosive substances. An equally notable engineering achievement was the building of a plant at Perryville, Maryland, in about 100 days in which to produce 300 long tons of ammonium nitrate daily by this process. The plant was built of concrete, tile and steel of the most approved construction and cost about fourteen and a quarter millions of dollars. The results of its operation exceeded all requirements.

An achievement of a quite different character but of the highest order in novelty and importance was that of using crystals, such as those of tourmaline, quartz or sugar, with which to measure the pressures exerted by explosives as they explode. It is important to know this with a high degree of precision for use in designing and operating guns, in charging mines and planning explosives operations. Heretofore attempts to measure these pressures have been made by the deformation of disks of copper or lead of known form and dimensions, but since the inertia of these bodies must be first overcome and, since, owing to elasticity, they tend to regain their original form and dimensions, the methods were in error to an unknown extent. It was known that when asymmetric crystals, such as those of tourmaline, quartz or sugar, were subjected to pressure they acquired electric charges, which M. Curie had found were proportioned to the pressures put upon the crystal, and the electricity thus generated by pressure was styled piezo-electricity. Sir J. J. Thomson applied piezo-electricity to the determination of the explosion pressures of submerged guncotton by placing a plate of tourmaline within the primary explosion area, the plate being connected on each face to a conductor which led to an aperture through which a stream of electrons emitted from a heated tungsten filament was led, and the extent to which this stream was deflected was then noted. Or, in order to produce a pressure-time curve, the stream of electrons was at the time of deflection exposed to the influence of a rapidly alternating magnetic field. This method

is applicable to explosions of gaseous mixtures as well as to those of ordinary explosive substances and can be employed in the study of the pressures occurring in internal combustion engines as well as those in mines or guns.

An unexpected feature was the reduction in the cost of explosives in the United States as the war progressed. This is statistically shown in Bulletin No. 56 of the War Industries Board by C. L. Fry, and it was due to the exercise of good management and to improvements in plan and methods which resulted in increased economies in operation and greater outputs in the face of rising prices for labor and materials. It was also due to the relatively small loss from explosions in manufacture, storage, or transportation. It is true that there did occur explosions of unparalleled magnitude at Black Tom Island, London, Halifax, N. S., where 2367 tons of picric acid, 250 tons of TNT and 62 tons of nitrocellulose, or 2679 tons in all, exploded on the S.S. *Mt. Blanc*; and at Morgan, N. J., where 4225 tons of ammonium nitrate, 370 tons of smokeless powder and 187 tons of TNT were involved; and it is also true a large number of explosions occurred in the industry during the period of the war. But accidental explosions are a feature of this extra-hazardous industry and no true idea can be had of war-time experiences except through a statistical comparison with peace-time data. This cannot be done in this matter for the United States, since until the declaration of the war the National Government had not exercised any supervision over the explosives industry. But Great Britain has done so in its domain since 1875, and H. M. Inspectors of Explosives in the last annual report give a statement of conditions from Aug. 4, 1914, to Nov. 11, 1918. In this report it appears that there were produced during this time 445,559 tons of explosives and 11,725,000,000 pieces of ammunition and that the average number of persons employed was 61,807, with a maximum of 86,555. Yet, notwithstanding the fact that work was carried on under high pressure, that most of the employees were inexperienced, and that they were supervised largely by

equally inexperienced officials, there were but 1.25 per 1000 killed per annum during this period, while for the last previous five-year period in peace time the killed were 1 per 1000 per annum.

Some data as to the extent to which explosives were used may be of interest. Naturally since magazine rifles, machine guns and rapid fire cannon were used extensively and large caliber guns, of greater caliber, more numerous than ever before, the expenditure of ammunition exceeded that ever known. All calibers above small arms used high explosive shell. High explosives were also used in mines and torpedoes, which attained dimensions greater than in former use, in depth bombs devised for attack on submarines, and in drop bombs designed for use from airplanes and airships.

Data for small arm ammunition is not at hand but of artillery it may be said that while the total number of rounds fired by the Union Army at the battle of Gettysburg was 32,781, the British Army at the battle of the Somme in 1916 fired 4,000,000 rounds; and that while the total number of rounds fired by the Union Army throughout the Civil War from 1861 to 1865 was 5,000,000, the United States, British and French armies in 1918 fired 160,615,000 rounds. Of high explosives it may be said that the 75-mm. shell originally designed for one-half pound of black powder, in 1918 contained 1.76 pounds of high explosive. The United States naval mine carried 300 pounds of TNT and there were 70,000 of them anchored in the North Sea mine field. The charge used in blowing up the Messines Ridge is stated to have been 466.6 tons in weight, consisting principally of TNT. The largest single charge previously recorded was 141 tons, principally rackarock, used in blowing up Flood Rock at Hell Gate, N. Y.

X

THE CHEMICAL WARFARE SERVICE

CLARENCE J. WEST

CHEMISTS have always played a certain rôle in modern warfare. This rôle, however, was always more or less superficial. It consisted simply in an attempt to perfect gun powder and to suggest new and more powerful explosives, not to make war more horrible but to shorten, if possible, its duration. The chemist was buried in his laboratory, in Government arsenals or in the plants of privately owned ammunition companies. He played no prominent part, as did the engineer or the medical man. The introduction of poison gas and the flaming liquid gun by the Germans during the year 1915 changed this relationship and as the war progressed the chemist came to play one of the leading rôles. It is not fair to the other scientific men to call the late war "a chemist's war," but we must admit that his was no mean part and that it was very largely due to the tremendous advances in chemical knowledge and the extensive gas program laid down by the Allies that the war terminated when it did.

This honor is to be equally divided between the academic and the industrial men. Even though industry is always using the results of purely scientific research, there has been a tendency on the part of the industrial men to decry the value of academic research. This feeling was entirely lost sight of during the past struggle and the two great classes of chemists worked hand in hand, often in the same office or laboratory, in order that a common end might be gained. No greater example of

coöperative research will ever be found than that of the Chemical Warfare Service.

Too much cannot be said of the coöperation of our Allies in this connection. Nearly two years had elapsed between the time of the first gas attack on April 22, 1915, and our entry into the war. During this time France and England had to face and to solve, as well as they could, all the new and perplexing problems of Chemical Warfare. While the American army had many of its officers observing the new and rapid advances in the various forms of fighting, and while the physician was studying the new methods of medicine and surgery, apparently little attention was paid to questions relating to the use of poison gases. We were, therefore, almost as unprepared to face these problems as were the Allies in the spring of 1915. Once, however, we took upon ourselves the task forced upon us by the barbarous acts of the German nation, the Allies put at our disposal all the vast store of information gained during their two years of experience. Not only did they send us reports of work done and samples of the materials used by their armies, but they sent to us trained men, with knowledge of field and factory conditions, who were of inestimable value to our scientists. We will always remember, with deepest gratitude and respect, such men as Lieut. Col. Auld, Major Le Sueur, Major Brightman, Dr. Grignard and their colleagues, who so ably and so willingly contributed to the success of our Chemical Warfare Service.

Census of Chemists. At the beginning of the war in 1914, there were no indications that the chemist would be of any more value than in previous wars. True, it was early evident that the need of ammunition would be very great, but even this increased output would require but a few of the hundreds of chemists of military age. Therefore, when the real need did come, England found that her young men, at least, were all in the trenches and that many of them had already given their lives in the great cause. In order that America might avoid this loss of potential power, the first task undertaken by the

American Chemical Society in coöperation with the Council of National Research was a census of the chemical talent of the country. Since 14,500 of the 17,000 chemists were members of this great organization, the Society was able to furnish the Government with such information that, if a man was needed for a particular work, the Government was able to place its hand on the right man and send him to the right place. It must be said in passing that this did not always please the younger men of the chemical fraternity. Many of them wanted to see the action of real fighting in France. Some of them tried to do so by enlisting in the actual fighting units of the army. While a few succeeded in this, so complete was the information of the War Department that the majority were secured for the more important task of the preparation of chemicals for the use of the men who could not do this because of the lack of training or experience. The value of this was evidenced by the remarks of Secretary Baker at the Philadelphia meeting (1919) of the American Chemical Society.

Early Organization. The first man to recognize the need for a systematic and detailed organization to study chemical warfare was Van H. Manning, the Director of the Bureau of Mines. In February, 1917, when war between the United States and Germany seemed inevitable, Mr. Manning pointed out to the War Department the peculiar manner in which the Bureau could be of value in the study of the gas mask. On April 4th, the first conference was held, with representatives of the army, navy, and Bureau of Mines present. This meeting may be considered the organization of the American University Experiment Station of the Bureau of Mines, later to become the Research Division of the Chemical Warfare Service. Mr. (later Colonel) George A. Burrell was called to be in charge of this work. At once the station began to grow; prominent chemists were called from all walks of life to fill the ever growing need of information and more information. The story of the development of this wonderful chemical organization has been vividly described by Colonel Burrell and the other

members of the Chemical Warfare Service (see the "Journal of Industrial and Engineering Chemistry" for 1919 as space does not permit its repetition here).

The Gas Service. The arrival of our army in France and a study of conditions first hand soon revealed to General Pershing that it was absolutely necessary to have a laboratory on the field. To meet this need the Gas Service, A. E. F., was organized with Colonel (later Brigadier General) Amos A. Fries as Chief and with Colonel Raymond T. Bacon as Chief of the Technical Division. Although this service was organized in September, 1917, it was not until January, 1918, that the first laboratory unit sailed. This grew into a very important organization with a defense, offense, technical and field division, and carried on very important laboratory and field investigations.

Meanwhile at home the research, development and manufacturing sections of the Chemical Warfare work grew by leaps and bounds and in order to care for all the needs of our rapidly expanding army, many branches of the Service became involved in the schedule of production. The result of this necessarily led to some confusion and there were constantly growing demands for coördination.

The Chemical Warfare Service. The result of these demands led to the organization in July, 1918, of the Chemical Warfare Service, with Major General Sibert as Chief. All the units of the army engaged in the development or production of chemical warfare materials were assembled into this new organization. It was finally composed of the following divisions: Headquarters, Research, Gas Offense, Gas Defense, Development, Proving, European (A. E. F.), Medical. Each of these was under a competent chief, reporting to and responsible to General Sibert. Out of almost chaos came order. The work was coördinated and harmonized, each Division performing its own duties and working with the other Divisions in a wonderful way. Because of the signing of the Armistice, the Service was unable to show its full power of accomplishments. Some of its achievements will be discussed below, and

these will indicate the possibilities of the organization when it was forced to discontinue its activities on November 11, 1918.

The Development of Chemical Warfare. We have traced the organization of the Chemical Warfare Service and have seen that it grew to meet the ever increasing demands of gas warfare. Let us now examine briefly the development of chemical warfare itself.

Chlorine was first used in chemical warfare, both because it was a commercial product and readily accessible and because it was a nearly ideal gas for a cylinder attack. For this purpose a gas had to be easily compressible, heavier than air, and with a boiling point sufficiently low to cause it to volatilize easily and rapidly; it had to be toxic in relatively low concentrations in air and it should be rather stable toward other chemical agents. In all but the last respect, chlorine fulfilled all these requirements. For months before the first gas attack on April 22, 1915, the Germans must have been busy, building up a supply of chlorine, developing a gas cylinder, providing a mask to protect their own troops and in training the "Pioneers," the men who were in charge of the actual gas attacks. We are all acquainted with the success of that first attack, and only the German's lack of faith in his own weapon prevented him from a clear sweep of Calais and England. About December, 1915, phosgene was mixed with the chlorine. This added a greater toxic value to the gas mixture and introduced a second very valuable property, namely, the delayed action of the phosgene. Men might go for twelve hours after being gassed with phosgene before realizing the fact, and then only became aware of it, when, on slight exertion, they dropped from heart disorder.

The cylinder attack had very decided disadvantages and the German soon learned that he could accomplish the same end with a much greater degree of safety by using the poison gas in shell. Indeed, gas shell, containing lachrymatory (tear producing) gases, were used almost simultaneously with the first cylinder attack. The first toxic gas to be used was superpalite,

usually mixed with phosgene. This was almost as toxic as phosgene and had the advantage of being more persistent, since its boiling point was very much higher. The manufacture of this material, however, wasted tremendous quantities of chlorine and its use gradually decreased.

With the summer of 1916, we see the introduction of special gases. The first of these was chloropicrin. While not quite as toxic as superpalite, chloropicrin possessed the peculiar physiological property of causing vomiting. It was used very effectively in connection with other lethal gases, the chloropicrin causing the men to remove their masks in the poisonous atmosphere, and thus producing many casualties. With the increasing degree of protection, chloropicrin lost its great military value. Then the Germans sprung their Sneezing Gas (diphenylchloroarsine). This was used in shells carrying a high bursting charge. The explosion of the shell scattered the Sneezing Gas in the form of a very fine cloud of particles. While the charcoal of the mask will remove most poisonous gases, it has no protective power against clouds or mists. The Sneezing Gas passed through the best canister, and through its peculiar physiological effect caused great discomfort to the men and numerous casualties through forcing the men to remove their masks. Lachrymators were also used extensively, especially in territory where neutralization alone was desired. Because of the low concentrations in which lachrymators are effective, they are very economical as far as the amount of gas used, and very valuable from the military point of view, because they cause the wearing of masks and thus reduce the efficiency of the men.

The crowning achievement of gas warfare was the introduction of mustard gas. The name "blistering gas" indicates its peculiar physiological property. This is a high boiling substance which is very persistent. It has been known to cause casualties seven to ten days after the firing of the shell. It produces a severe burn and the casualties are usually out of action from three weeks to three months or even longer. A

place that is apparently free from gas may become dangerous from the material volatilized from the soil by the heat of the sun's rays. It is stated that the British suffered more casualties from mustard gas the first month after its introduction than during all the earlier part of the war. Of the casualties in the manufacture of poison gases, two-thirds were due to mustard gas. While the later gas program of the Allies included phosgene, chloropicrin, lachrymators, diphenylchloroarsine and certain other gases, the principal attention was given to the manufacture of high quantities of mustard gas.

Equally important are means of defense. Throughout the history of Chemical Warfare we see the art of defense keeping pace with the new means of offense. While it was comparatively easy to furnish protection against chlorine and phosgene, the special war gases demanded increased study of absorbents, such as charcoal, soda lime, and specially activated mixtures. The first British box respirator is a marvel of achievement, and will always be a monument to the memory of the late Lieut. Col. Harrison of the British Anti-Gas Committee. And yet one can imagine the disagreeable task of wearing this mask with its tight nose stopper and uncomfortable mouth piece when charging over the top with fixed bayonet and the determination to win. And while we may say that the problem of defense was satisfactorily solved, we forget the discomfort of the man at the front in so doing. The French early recognized this fact and developed their Tissot mask. This removed both the nose clip and the mouth piece and increased the comfort of the mask many fold and the efficiency of the men at least 50 per cent. While the later developments in American practice produced a Tissot mask that combined a high degree of protection with a maximum of comfort, the unfortunate fact remains that this did not help the man at the front in the least. At the signing of the Armistice he was still wearing the Standard Mask with all its inconveniences.

Research Method. It is worth while at this point to discuss the methods used in chemical warfare research. Fundamen-

tally, of course, the methods used did not differ from those of the individual sciences. But here there was a combination of all sciences practically; the results of one set of tests decided whether other tests should be made and the combined results decided whether the "gas" was suitable for military purposes. The material in question may be one that was already used by the Germans, it may have been found from a search of the literature, or it may be the result of analogy or pure inspiration. The substance was prepared by the Offense Section, research ability being used to secure the cheapest and most efficient laboratory method. The first test is to determine the toxicity, if the material is simply a lethal gas, or if a special gas, its lachrymatory power, blistering power, etc. If this report is favorable, then real research work begins. Methods of analysis are worked out, both for the pure material and for air mixtures. These methods are used in testing the efficiency of the standard respirator against varying concentrations of the gas in air. The stability when fired in shell is determined, and, if the material is a solid, methods of dispersing it as a cloud or mist. If the canister does not furnish sufficient protection, changes are made in the proportion of the present ingredients, or new mixtures or compounds are tested until satisfactory protection is afforded by the canister. The results of all the tests so far are then critically analyzed, and a decision reached as to the probable suitability of the material as a poison gas. If this decision is favorable, then more work is undertaken. First of all it becomes necessary to work out a commercial process of preparing the substance. Large firing trials are made to determine whether the boosters are suitable to secure the maximum effect from each shell. The pharmacological effect of the material is carefully studied, and the animals that have been "gassed" are studied by pathologists. These results are then used to ascertain, if possible, the therapeutic measures to heal the lesions caused by the "gas." If the results of all these tests still point to the success of the material, it is then ready to be launched as a new poison gas.

SOME OF THE RESULTS

It is possible to pick out only a few of the many scientific and technical problems which met the chemist when the United States entered the war and which increased as chemical warfare became more and more complex, and to show the results achieved.

Charcoal. The first problem naturally to engage the attention of the army was that of defense. The Germans were using poison gas. And whether we used it or not, it was necessary to protect our men against German gas. This meant gas masks. And while for comfort and efficiency the face piece was very important, for protection the canister was the vital factor. Of the canister, the filler used was really more important than the shape and size of the tin box and even than the method of filling. From the experience of the British Gas Service we knew that charcoal and soda lime were the necessary components of the filler. We needed to know the general requirements of gas mask absorbents, methods of manufacture, methods of filling, methods of testing and how to secure the maximum efficiency for the greatest number of gases. At the close of the work we had learned that the following were some of the necessary properties of a charcoal (not necessarily all). It should have a very high rate of absorption, or a high degree of absorptive capacity. A man, when exercising, breathes about 60 liters of air per minute. This corresponds, when calculated on the basis of the regular army canister, to an average linear air velocity of about 80 centimeters per second. This is obviously a very brief interval in which to remove toxic materials from the air. Furthermore, this absorption must be surprisingly complete. The total result is that an absorbent for use in a gas mask must be capable of reducing the concentration of gas from say 1000 parts per million to 1 part per million or less within 0.1 second. Of equal importance is the *absorptive capacity* of the absorbent, and further, that the gases be held firmly by the absorbent. The material used must be of

a type which can be relied upon to give protection against practically any toxic gas. The absorbents must be mechanically strong in order to retain their structure and porosity under very rough handling and jolting. They also must not be subject to abrasion, for the fines would plug up the canister or cause serious channeling. The materials used as absorbents must possess a very considerable degree of chemical stability; this stability is composed of many factors, and places a very serious limitation upon the materials which can be satisfactorily used. The result of a very extensive series of investigations, having as their object a low breathing resistance canister, has shown that, in general, the use of large cross-sectional area of relatively fine granules gives the best all round results. Then, of course, such questions as ease of manufacture, and cheapness and availability of raw materials must be considered.

The only single substance which even approximately fulfills all the above requirements is charcoal. From a theoretical study, it has been shown that the essential characteristics of active charcoal are: it must have high and fine-grained porosity; it must consist of amorphous base carbon; it must be free of absorbed hydrocarbons. On the basis of these considerations the preparation of active charcoal resolved itself into two steps: the formation of a porous, amorphous base carbon at relatively low temperatures, and the removal of the absorbed hydrocarbons from the primary carbon and the increase of its porosity. The first step involves the destructive distillation of a material (cocoanut shell was found the most suitable wood) at relatively low temperatures, in thin layers so that the deposition of inactive carbon from the cracking of hydrocarbons, would be avoided. The second step is much more difficult, and was finally accomplished by oxidation with air, steam or carbon dioxide steam, all of which were used in the manufacture of gas mask carbon.

In addition to the use of cocoanut shell (Dorsite), other sources were developed, such as anthracite coal (Bachite), and a synthetic product made by carbon manufacturing process

from lampblack, powdered coal and other suitable materials (Carbonite).

Soda Lime. Charcoal alone is not a satisfactory all-round absorbent because it has too little capacity for certain highly volatile acid gases, such as phosgene and hydrocyanic acid and also because an oxidizing agent is the best means of handling certain gases. It has, therefore, been found that the use of an alkaline oxidizing agent in combination with the charcoal is advisable. The material actually used was a soda lime containing sodium permanganate. The ratios used were 60 per cent. 6-14 mesh cocoanut shell charcoal and 40 per cent. 8-14 mesh soda lime permanganate granules. The last mixture suggested, which would have had a distinctly greater all round efficiency, was composed of 75 per cent. specially impregnated cocoanut charcoal and 25 per cent. soda lime containing no permanganate.

Due to the inherent nature of soda lime, it was a very difficult and complicated problem to determine the best balance of the requirements. The activity is not of vital importance except in the case of phosgene. Capacity is of the greatest importance since the soda lime is relied upon to hold in chemical combination a very large amount of toxic gas. The question of chemical stability and mechanical strength demanded much serious thought before they were satisfactorily secured.

A typical formula for gas mask soda lime is:

Hydrated lime	45 parts
Cement	14 parts
Kieselguhr	6 parts
Sodium hydroxide	1 part
Water	33 (approx.)

The lime constitutes over 50 per cent. of the finished dry granule and is responsible in a chemical sense for practically all of the gas absorption. The cement furnishes a degree of hardness adequate to withstand service conditions. The loss in porosity due to its use is counterbalanced by the introduction of

keiselguhr, which seems to increase the degree of hardness. The sodium hydroxide served to give the granules considerable more activity and at the same time maintains roughly the proper moisture content.

The above mixture is dried to about 8 per cent. moisture and then sprayed with a solution of sodium permanganate. This acts as the oxidizing agent in the finished granule. Of the five commercially available permanganates, sodium was the only one meeting all the requirements. It makes up about 3 per cent. of the granule, the moisture content of which ranges about 13 per cent.

The use of large amounts of sodium permanganate necessitated the working out of a method for its manufacture. It was found that a 30 per cent. solution could be prepared by the fusion of sodium hydroxide and manganese dioxide, leaching, and chlorination of the sodium manganate in the presence of a catalyst. Another method developed consisted in the electrolysis of sodium carbonate solution in a diaphragm cell with ferro manganese anodes. The current density used is about 120 amperes per square foot and the temperature may be about 20°C. The anodes gradually accumulate a skin of oxides of iron, manganese and silicon, which is easily removed every 24 hours by sand blasting. It is not feasible to run beyond an 8-12 per cent. solution of sodium permanganate, which is then concentrated to about 30 per cent. Under war conditions, the cost was estimated at about 60 cents per pound.

CARBON MONOXIDE ABSORBENT

Another very important phase of work on absorbents was concerned with carbon monoxide. While not sufficiently toxic to be used as a poison gas, it is a source of serious danger both in marine and land warfare. It is encountered as the result of defective ventilation in boiler rooms of ships, in pill boxes and in tanks and in mining and sapping work. In times of peace, the gas is also a serious hazard and it was realized that the successful solution of the problem of protection against

carbon monoxide would be of great commercial and industrial importance. Because of the peculiar physical and chemical properties of the gas, its removal from the air is very difficult.

Two mixtures were finally discovered which were satisfactory absorbents. The first of these consisted of fuming sulfuric acid and iodine pentoxide, with pumice as the carrier (Hoolamite). This mixture is active for 2 hours at room temperature (the gas-air mixture being passed at the rate of 500 cc. per minute per sq. cm. of cross section) and almost as long at 0°. About 75–80 per cent. of the iodine pentoxide is utilized during this time. The sulfur trioxide which is given off is removed by the use of a layer of active charcoal beyond the carbon monoxide absorbent. But the sulfur dioxide, which is slowly formed as the result of this absorption, gives serious trouble on long continued use of the canister. Another disadvantage arose from the fact that heat was evolved in the reaction of carbon monoxide and the absorbent. This could be overcome by the use of a cooling attachment (a metal box filled with sodium thiosulfate-pentahydrate) though it nearly doubled the size of the canister. Still another disadvantage of this absorbent was the fact that it absorbed enough moisture from the air of average humidity in several hours to destroy its activity.

Incidentally a simple and inexpensive method for the production of iodine pentoxide was perfected. It was also shown that the green color resulting from the action of carbon monoxide on Hoolamite could be used as a very sensitive detector for the presence of carbon monoxide in air.

The second and far superior absorbent consists of a mixture of metallic oxides. This originated from the observation that a specially precipitated copper oxide activated with 1 per cent. silver oxide was an efficient catalyzer for the oxidation of arsine by the oxygen of the air. This led to the study of other oxides and mixtures and finally it was found that a three-component mixture of cobaltic oxide, manganese dioxide and silver oxide, in the proportion of 20: 34: 46, prepared by the interaction of silver permanganate with moist hydrated cobaltic

oxide, and a mixture of equal parts of manganese dioxide and silver oxide, acted as catalyst in the oxidation of carbon monoxide by the oxygen of the air. Many mixtures of widely different composition showed catalytic activity. Since it was found that the minimum silver oxide content decreased progressively as the number of components increased from 2 to 4, a four-component mixture was finally chosen as the standard mixture (Hopcalite I). This consisted of 50 per cent. manganese dioxide, 30 per cent. copper oxide, 15 per cent. cobaltic oxide and 5 per cent. silver oxide. The first three components were precipitated and washed separately, and the silver oxide was precipitated in the mixed sludge. After washing, the sludge was run through a filter press, kneaded in a machine and the cake dried and ground to size. Each step required careful control to insure a product at once active, hard, dense and as resistant as possible to the deleterious action of water vapor.

Because of the catalytic action, a depth of one and a half inches was found sufficient in the canister (300 gm.). Since the normal catalytic activity of Hopcalite requires a dry gas mixture, it was necessary to provide a drier at the inlet side of each canister. Dry, granular calcium chloride proved a suitable material for this purpose. Although there is a considerable heating effect when the carbon monoxide is oxidized and also in the drying of the gas mixture, the heat capacity of the canister and its contents and the rapid dissipation of heat by radiation and conduction prevents the effluent air from reaching higher than 50° during the first fifteen minutes (against a 1 per cent. mixture) and from rising higher than 90° even after several hours. The cooling effect was considerably increased by the use of sodium thiosulfate pentahydrate.

The canister, as developed, is now being used in the industry and in mine rescue work.

AMMONIA ABSORBENT

Still another problem concerned itself with an absorbent for ammonia. Here again the work was a direct outcome of the

needs of the navy, but this absorbent has already found very practical use in connection with refrigeration plants. The previous protection had been obtained by the use of pumice stone impregnated with sulfuric acid. Such protection had serious disadvantages. These were largely overcome by the substitution of certain salts which form metal-ammonia compounds. Of these, cobalt chloride or copper sulfate are by far the best absorbents for ammonia. The pumice is added to a solution of copper sulfate and the mixture heated until the salt crystallizes on the pumice and the crystals are nearly dry. Moisture that may be given off by the absorbent is removed by placing a one inch layer of charcoal or preferably silica gel at the top of the canister. With 45 cu. in. of this material, protection is afforded for 5 hours against 2 per cent. ammonia (man breathing at rest) or for 2.5 hours against 5 per cent. ammonia. For periods over 15 minutes 2 per cent. ammonia is unbearable, due to skin irritation. The copper sulfate canister has been named the Kupramite ammonia canister and is being manufactured by at least two concerns at the present time.

Absorbents, however, were only one, though a very important phase of the work. The great disadvantage of the British Standard Box respirator was the fact that the design of the face piece, consisting as it did of a nose clip and mouth piece as a "secondary line of defense," decreased seriously the efficiency of the men. The French early recognized this and developed their Tissot type of mask for the artillery men. While the English apparently never saw fit to develop this further, the Chemical Warfare Service saw its great advantage and modified it in various ways, producing the Kops-Tissot, the Akron-Tissot, the Miller-Tissot and the Lakeside-Goodrich masks. All of these were designed upon the same basic principle. The air, passing through the canister, was drawn up into the mask so that it passed over the eye pieces before being breathed. In doing away with the mouth piece and nose clip, it was essential that the rubber face piece should be so reinforced that it would not be easily torn. This involved intensive

research on fabrics and led to a very satisfactory material. Similarly each piece of the mask led to a search for the most desirable design and the best material. In passing, the eye piece may be mentioned. Triplex glass was soon learned to be the most satisfactory for eye pieces, but the manufacturers almost despaired of its production, the per cent. of rejects being so high. Again science proved its worth, for the Service was able not only to reduce very materially the number of rejected lenses but was able to speed up production to the point where the needs of the Gas Defense Service were adequately met.

OTHER DEFENSIVE METHODS

The introduction of mustard gas brought other problems of defense. The viscous nature of this substance, with its high persistency and its capacity to produce severe burns even in low concentrations of vapor, suggested the need of protective ointments and protective clothing. Much effort was expended, by the Medical as well as the Chemical Section, to devise an ointment that might act as a protection to the body. While an ointment was obtained that appeared to give protection against relatively high concentrations of the gas over short periods of exposure, it was learned after continued experimentation that no protection could be expected under field conditions, namely, a low concentration and a long period of exposure. Attention was also directed to the production of various articles of protective clothing, such as underwear, outer clothing, gloves, boots, and masks for horses and dogs. Various types were developed for factory use in the manufacture of poison gases, and also for the front, though they never were used at the front.

ORGANIC RESEARCH

The organic chemist found many fields for his endeavors. The first problem to engage his attention was a survey of the whole field of organic chemicals, in order that he might have a clear idea of the possibilities of chemical warfare. This really

did not lead very far at first, and besides, years of research and chemical reading had given the German an advantage. The best results came from individual fields of research. Here, again, we must acknowledge our debt to our Allies, for all their experimental results were freely placed at our disposal.

The preparation of chloropicrin and superpalite was first considered. Chloropicrin was soon placed on a manufacturing basis, the well-known reaction between bleaching powder and picric acid being used. The logical method of preparation should be from an aliphatic compound, but no research revealed the proper conditions. The English later found that chlorine gas could be substituted for bleaching powder with a great economy of chlorine, but the method was never used in American practice.

Superpalite was a favorite poison gas with the Germans and was extensively used in the first gas shell. American chemists could never discover any economy in its preparation, and never used the material. It was found that chlorination of methyl chloroformate in steps in ultraviolet light gave the substance in fair yields but with a very great waste of chlorine. After a great many fairly successful trials the matter was permanently dropped.

One of the large tasks followed the introduction of mustard gas (dichloroethyl sulfide). The British were able to identify the new shell filling without difficulty, because they had previously suggested its use. Their analysis indicated that the material had been prepared by the academic method of Victor Meyer, through the action of sodium sulfide on ethylene chlorhydrin, followed by the action of hydrochloric acid. The logical method seemed to be the action of ethylene upon sulfur chloride. Several American chemists tried this reaction, but were unsuccessful in obtaining mustard gas, because of their lack of information regarding its chemical properties. It seemed necessary, therefore, that attention should be concentrated on the method as used by the Germans and that very rapid progress should be made. This method resolved itself

into at least three separate and distinct problems (a) the production of ethylene, (b) the reaction between ethylene, chlorine and water, to form ethylene chlorhydrin, (c) and the production of mustard gas from this compound. The first problem, ethylene, was successfully solved by the action of kaolin upon ethyl alcohol at a temperature of 500-600°. A distinct development was accomplished in the discovery that the reaction could be controlled more uniformly and a purer ethylene obtained, if steam was introduced with the alcohol vapor in the ratio of one to one by weight. The British found that coke saturated with phosphoric acid also provided a very suitable catalyzer for the removal of water from alcohol. The second and third problems connected with this synthesis were never satisfactorily solved from the commercial point of view, for in the midst of this development Pope in England discovered the conditions under which ethylene could be made to react with sulfur chloride. Because of the simplicity of this reaction, the Meyer method was entirely displaced by the sulfur chloride reaction. The last word was added by the development of the Levenstein "reactor." The details of these processes were communicated to American chemists and adapted to American practice. The success of the method is evidenced by the fact that at the signing of the Armistice, the Allies were producing many times the amount of mustard gas that the Germans were capable of producing by their method, and also by the fact that the Germans were rapidly replacing the Meyer method by the Pope method, details having been captured from some Allied source.

Another intricate field of research was found in the arsenicals. The first member of this group was diphenylchloroarsine, used as a sneezing gas by the Germans. Although this was an old compound (first prepared in 1885), there was no satisfactory method of preparation on a large scale. It was finally discovered that it could be prepared by the interaction of triphenylarsine and arsenic trichloride. The Germans also introduced a second type of arsenical, ethyl dichloroarsine. Apparently they used this because there was no suitable method

of preparing methyl dichloroarsine, which is a more satisfactory substance. The Chemical Warfare Service was successful in its efforts to develop methods for preparing both of these substances.

Methyl dichloroarsine can be made in three stages: Sodium arsenite is prepared by dissolving arsenic trioxide in caustic soda solution; the action of dimethyl sulfate at 85° yields disodium methyl arsenite, $\text{Na}_2\text{CH}_3\text{AsO}_3$. Upon passing sulfur dioxide through the solution, methyl arsine oxide results. This is then converted into the chloride by passing hydrogen chloride (gas) into the mixture, and the chloride is distilled and condensed.

Lachrymators also received a great deal of attention. The French method for the preparation of brombenzyl cyanide, which is probably the best lachrymator used on the field (though more satisfactory ones were developed and would have been used during 1919 had the war continued) was improved and placed on a manufacturing basis.

A large number of other compounds were studied, many of which were discarded as useless while others were developed to the point where they could have been placed in large scale production had the need manifested itself.

INORGANIC RESEARCH

Inorganic chemistry does not offer as many interesting problems nor as spectacular ones as does organic chemistry. Among the problems successfully solved were the large scale production of hydrocyanic acid (the method for which was later used technically for its manufacture as an insecticide), arsenic trichloride, nitrogen peroxide, arsine and fluorine. Fluorine may be obtained very satisfactorily by electrolysis of a fused bath of acid potassium fluoride at $225\text{--}250^{\circ}\text{C}$. in a copper containing vessel, using a graphite anode. It is probable that better results could be obtained by the use of a graphite anode, graphite diaphragm and a graphite containing vessel, the last serving as a cathode. Various derivatives, such

as boron trifluoride, were prepared, but no fluorine compound found any use in chemical warfare.

ANALYTICAL RESEARCH

As a preliminary to the study of the properties of toxic gases and of the means of defending against them, it is necessary to be able to detect and determine these gases. An analytical and testing section was, therefore, one of the first to be established and it was always busy in spite of the fact that all the other sections coöperated in developing methods of analysis and testing. The details of analytical methods are not specially thrilling to anybody except a technically trained man, so it will, perhaps, be sufficient to say that satisfactory methods were worked out for analyzing every toxic gas with which the Chemical Warfare Service had to deal. Three typical cases may be mentioned, however: the testing of canisters, the field tests for mustard gas, and the special paint for shell.

Canisters are tested on men and on machines. Multiple machines have been developed which will test eight canisters simultaneously at continuous flow of the gas-air mixture or at intermittent flow. The continuous flow machines are the easiest to construct and were made first. Since the man breathes through the canister intermittently, the results with the intermittent flow machines resemble more closely those encountered when masks are actually worn in gas. The intermittent flow machines are capable of wide variation both as to volume of air passing through and as to number of oscillations per minute. They can, therefore, be adjusted to simulate any type or rate of breathing. Comparison tests on men have shown that the intermittent machines give results in excellent agreement with man tests, are easier to run, and are much more accurate, because they do away with the personal idiosyncrasies of the men. This does not mean that man tests should be abolished. They must always be kept to provide for unexpected contingencies but they can be reduced to a minimum with a great saving of time and friction.

In the earlier man tests the men were sent inside a gas chamber; but afterwards the canisters were connected by tubing to the gas chamber and the men sat outside the chamber. This made it possible to run more tests simultaneously and had the further advantage that the man in charge of the testing could determine for himself whether any given canister had broken down or whether the report was due to nervousness on the part of the subject. All the toxic gases can be detected at concentrations which do no harm to the individual. There are two extremes to be guarded against. The man who is testing the canister may imagine that gas is coming through when that is not the case, or he may be so anxious to avoid giving a false report as to continue the test too long and consequently get gassed slightly. With the men accessible outside the chamber, it is a comparatively simple matter to guard against both these possibilities.

The man test is only run until gas is detected coming through the canister; but the machine test can be run farther. It is customary to designate the time at which gas can be detected coming through the canister as the "breakdown." Up to then all the gas was removed by the materials in the canister. The 99 per cent., 95 per cent., 90 per cent. points, etc., are the points at which 99 per cent., 95 per cent., 90 per cent., etc., of the gas is stopped and 1 per cent., 5 per cent., 10 per cent., etc., of the gas in the air comes through.

When testing the variations in absorbents, the absorbent is filled into a sample tube, of specified diameter, to a depth of 10 cm. by the standard method of filling, and gas passed through under definite conditions.

Trained observers can detect mustard gas by smell at 0.1 p.p.m. (0.0007 mg. per liter); but only for the first minute or two of exposure. Low concentrations of mustard gas vapors, when in contact with a dilute solution of selenious acid, produce an orange-colored colloidal suspension of selenium which gradually increases to a deep brick-red color in time if the concentration of mustard gas is sufficient. The test is sensitive to

about 1 p.p.m. (0.007 mg. per liter). This method is not specific because arsine gives a similar precipitate in less time than does mustard gas, and other compounds such as diphenylchloroarsine and butyl mercaptan give positive results. As against this, chlorine, hydrogen chloride, phosgene, chloropicrin and superpalite give a negative test even when present in fairly high concentrations.

While the copper flame test is not sufficiently sensitive to permit of direct detection of low but toxic concentrations of mustard gas, it has been found possible to modify the method so that one can detect 0.1 p.p.m. (0.0007 mg. per liter) or even 0.01 p.p.m. under special conditions. The principle has been embodied in a portable field apparatus. The method is really one for halogens and is not specific for mustard gas. Its usefulness in the field is questionable.

SMOKE

One of the most interesting scientific studies made was concerned with the theory of smokes. The concentration of the smoke was determined by precipitation in a modified Cottrell apparatus consisting of a central wire cathode surrounded by a cylindrical aluminum foil anode about 1/1000 inch in thickness. A 15,000 volt rectified direct current was used and complete precipitation was obtained with fairly concentrated samples of smoke even when drawn through the apparatus at a rate of about five liters per minute. The aluminum foil and adhering smoke were then weighed. Microscopic examination showed whether the smoke particles were liquid or solid. The size of the particles in a smoke can be determined ultra-microscopically with fair accuracy by measuring the velocity of a charged particle in an electric field of measured intensity, photographing the path of the particle while the direction of the electric field is reversed regularly by a rotating commutator whose speed is known accurately. When the convection due to the source of light is perpendicular to this motion, a zigzag line is obtained. Since about one-third of the smoke particles

are charged electrically, photographs of these oscillations show simultaneously the behavior of a large number of particles, thus simplifying the study of size distribution. For the more rapid study of smokes an instrument called the Tyndall meter was devised which measured the brightness of the Tyndall beam set up in the smoke to be examined. For low concentrations of smoke the brightness of the beam increases with the concentration and the degree of dispersity of the smoke material, so that if either factor remains practically constant the readings give a measure of the variation of the other.

Using the Tyndall meter, the rate of disappearance of smoke in a confined space was studied. The smoke gradually disappears, owing to coagulation, to settling and to the diffusion of the particles to the wall where they stick. The rate of disappearance was markedly increased by stirring the smoke. This rate increases with concentration of the smoke, owing to the increased chance for coagulation and removal by the walls. It is also greater for a finely divided smoke of a given concentration than for a coarser smoke owing to the increased opportunity for coalescence.

Several forms of smoke producers were developed for the navy as a protection against submarines. The Navy Smoke Funnel consists of a large horizontal cylinder approximately two feet in diameter and 10 feet long with a hand operated blast fan at one end to drive air through the funnel. The apparatus is placed on the deck of a vessel and if a submarine is sighted a dense smoke cloud of tremendous volume is produced for a period of thirty minutes. The Navy Smoke Box consists of a metal container 8" in diameter by about 26" in height, holding 100 lbs. of the Bureau of Mines Smoke Mixture. Attached to the cylinder are a float and a starting mechanism. When ignited and thrown overboard, this smoke box evolves a dense smoke for 9-12 minutes. An excellent smoke can also be obtained by spraying sixty per cent. oleum into the smoke stack of a ship. One drum of oleum (800 lbs.) will produce a smoke cloud of very large volume for one hour. The smoke

funnel and the smoke box are intended primarily for merchant vessels and the oleum smoke for fighting vessels. The oleum smoke is also very effective for concealing tanks, the oleum being sprayed into the exhaust.

For land work the Bureau of Mines smoke candle is more satisfactory than the smoke funnel or smoke box because the smoke can be generated simultaneously at a greater number of points along the front. It is ignited by means of an ordinary match and emits a white dense smoke of large volume for four minutes. A smoke knapsack was also devised consisting of two cylinders which can be carried on a man's back. The apparatus will give a dense cloud of smoke continuously for 15 minutes and the operator can regulate the production of the cloud instantly by adjusting the valves on the discharge pipe. Two men can cover the front of a company.

A Livens smoke projectile consists of a half-capacity 8-inch Livens drum adapted for combustion smoke by drilling holes around the top and filling these with fusible metal. The charge consists of the standard Bureau of Mines smoke mixture. Each shell will produce a smoke cloud of very large volume for five minutes.

OTHER PYROTECHNICS

Various other pyrotechnic devices were studied, developed or improved, mention of which may be made, but details of which must be lacking.

Gas shells were developed with special lead, glass or enamel lining, for use with the lachrymators in particular, but also with other gases. It was necessary to use special precautions with American filled shell, since they had to stand from three to six months before being used.

Hand grenades were developed and improved, all types (H. E., gas, smoke and incendiary) being studied. Special training grenades were developed, which later offered promise of field use.

Flaming liquid guns were developed but owing to the gener-

ally unsatisfactory nature of this form of warfare they were never used.

A great deal of work was done on the subject of incendiary drop bombs, shell, and darts. Of the drop bombs, a final successful type was a 100 lb. bomb, containing thermit and solid oil. Two types of darts were made. One was a non-penetrating type, weighing 5.6 oz. The other weighed 3 lbs., and had a penetrating head. Large numbers of each type were intended to be dropped from an airplane at once. The incendiary shell contained about 3 ft. of strands of chlorated jute rope.

Signal lights, flares and rockets were developed to a marked degree of perfection.

New types of Stokes mortars, Liven's projectiles and other ordnance material also were subjects of investigation on the part of the Chemical Warfare Service.

One interesting development had to do with new work on the French explosive, anilite. As used by the French, this explosive consists of two materials, kept in separate compartments in a two-compartment bomb. At the instant of fire, the two materials mix and explode. The mixture was finally made stable enough so that the two materials could be kept in a one-compartment bomb.

PERMANENT RESULTS OF THE WORK

In closing, we may quote Colonel G. A. Burrell:

"Out of the war, with its tremendous waste and suffering, have come many important and permanent things for humanity at large. This is especially true in this country, where the resources of the nation were not taxed to exhaustion or anywhere near it. Lessons have been taught in the aeroplane, transportation, food, and other services that will produce lasting and revolutionizing effects. The same is true of the Chemical Warfare Service. It is inconceivable that this service with a personnel of thousands of people, and comprising much of the best talent of the country, should not leave its imprint on

chemistry in this country. Organic, physical, biological, analytical chemists, etc., joined forces in one huge coöperative scheme. As a result, the organic chemist appreciated more fully the things in physical chemistry, and vice versa, and discovered how well the two branches working closely together could solve problems which might baffle one branch alone. Chemists learned more fully the great importance of certain branches of biological chemistry, and biologists got much from the other branches of chemistry. All learned the difficulties in the way of large scale manufacturing, and thought about all of their results in terms of production. They appreciated more fully than ever before that usually there exists a long and tedious path between laboratory test tube experiments and a successful manufacturing process developed from those test tube results. More research has been crowded into a short space of time by one single group than ever before. Chemists from all parts of the country met for a single purpose. High class men who had scarcely a speaking acquaintance with each other before the war became lasting friends, exchanging ideas on research, education, factory management, etc. Many young men of extraordinary latent ability have been developed, and some of the older men have shown their many colleagues that they were better adapted for and could do a first-class job along lines somewhat different from their accustomed duties. All of these things will have an important bearing on chemistry in this country. It may, indeed, constitute an epoch in the science.

“The direct fruits of the work are, of course, adapted for chemical warfare. It is possible that gas warfare may be outlawed because of its tremendous and fearful possibilities, so that many of the devices developed for chemical warfare will never be used in the future. On the other hand, the thought that went into the development of these devices cannot be destroyed. Men received an intensive training during the development by which they will profit.) It is also true that some of the results have direct and important applications to

the industries. This is certainly true of gas masks, and the absorbents in gas masks can be used for a diversity of purposes. The charcoal especially is an extraordinary absorbent or catalyst for a variety of purposes. Analytical chemistry received an impetus. It is undoubtedly true that never before was so much work done in so short a space of time on the refinement of analytical methods, necessary in order to measure gases in so great dilution as one part in ten million or twenty million. The Friedel and Crafts reaction was successfully put in operation on a larger scale than ever before in this country. For every offense problem there was a defense one, and the defense problems worked out for protection of American soldiers will bear fruit in protecting American workers in industries."

THE RÔLE OF
THE EARTH SCIENCES
IN THE WAR

XI

CONTRIBUTIONS OF GEOGRAPHY

DOUGLAS W. JOHNSON

ONE evening during the war there gathered at the Cercle Interallié in Paris a group of six or eight British, French, and American geographers and geologists, to compare notes and profit by the sharing of experiences. One had just come to Paris from British General Headquarters to search libraries and university laboratories for material needed in his work of supplying to the British armies information about the surface features of Northern France. Two were engaged as geographical experts on the French Comité d'Études, an organization charged with assembling scientific data which would be needed by the French representatives at the coming Peace Conference. Another was a member of the "Inquiry," a similar organization created in America by Colonel House at the direction of the President, and was at that time in Paris on duty for the "Inquiry" and as foreign representative of the Division of Geology and Geography of the National Research Council. Three were members of the Commission de Géographie, a branch of the Service Géographique of the French Army, occupied with the task of supplying the fighting forces of France with detailed geographical information about every region where those forces might be called upon to operate. One had assisted in training future officers of the American Army in geographical methods, and was now at the head of a war work bureau in France. It is a significant fact that the hazards of war could throw together in one place such a group of men, each of whom had been actively engaged in placing

earth science at the service of the Allies in order to hasten the day of victory. And the fact loses none of its significance when we add that not one of these men was satisfied that full advantage was being taken of the possibilities of his science as an aid in war.

It is not the purpose of the present writer to criticize the shortcomings of our own or any other government in utilizing earth science in the military program. It is rather my purpose to regard the brighter side of the shield, and to show by a brief review of pertinent facts that geography and geology did at least play an important rôle in the common task of wresting victory from the enemy. In accomplishing this purpose I cannot pretend to describe, nor even mention, all the channels through which the geographer and geologist made their important contributions. I must content myself with a very imperfect account of some aspects only of the work done in these two sciences, aspects which happened to fall under my personal observation. Fortunately, that of itself is sufficient to demonstrate the great possibilities of these sciences as military adjuncts, should their full strength ever be mobilized in the country's service. Let me begin at random with a short statement of some of the first efforts of our British colleagues.

Early in the war Dr. H. N. Dickson, Professor of Geography at University College, Reading, appreciating the importance of geography in connection with military operations, sought to establish a geographical bureau in connection with one of the departments of the British Government. At that time the War Office was so crowded with work that he turned to the Admiralty where there was less confusion, and under its auspices established a geographical bureau manned by a staff of men and women who were for the most part volunteers serving without pay. At the beginning his staff was housed in the rooms of the Royal Geographical Society, but it soon increased to such a size that special quarters were necessary, and these were secured by utilizing Hertford House in Manchester Square, an art gallery containing the Wallace Collections. The

collections were in large part removed, temporary walls and doors were erected, and a great staff of workers was soon turning out large volumes of geographical material for use by the British Army and Navy. Here the visitor found one gallery filled with long tables, each table devoted to a particular region such as Hungary, Belgium, or Serbia, filled with appropriate books and maps, and presided over by a specialist assigned to prepare a monograph on that region. A number of assistants, most of them men and some of them army officers, served under each specialist. In another gallery a corps of translators, mostly women, were at work translating and abstracting such foreign reports as the specialists and their assistants might desire. Two other rooms were equipped with drawing tables, and here, perhaps, a dozen or so draughtsmen and cartographers were busy making maps. One or two rooms were devoted to the meteorological staff, which assembled data and prepared maps and charts for this branch of the service. It was an impressive sight to witness this great body of scientific workers busy at the task of collecting geographical data for the use of Britain's fighting forces.

Many of the reports prepared by this geographical staff were of a highly confidential character; but it is permissible to state that the documents issued included a series of "Hand-books" describing the climate, topography, economic resources, transportation routes, and political geography of the many regions in which the British soldier might be called to fight in a world war; more elaborate "Manuals" of certain regions or problems of special significance, accompanied by Atlases of detailed maps portraying the topography, geology, rainfall, economic products, railways and other lines of communications, distribution of races and languages, and other geographical data which might be useful in very detailed studies; new maps of regions for which satisfactory cartographic material had not previously been published, and special maps and reports to elucidate a variety of problems for the solution of which different departments of the Government asked geographical

assistance; and charts of pressures, winds, and other meteorological elements for use by the flying forces of both the army and navy. Much credit is due to Professor Dickson for foreseeing, and to his large staff of assistants for supplying, a wide range of geographic needs of Britain's fighting machine.

But it was not alone in the Admiralty that geographic work for war purposes was being prosecuted, although we have seen that Professor Dickson found a better opening there than in the War Office. The Department of Military Intelligence of the latter bureau included in its complex organization the Geographic Section of the General Staff, whose chief was Colonel W. C. Hedley, and under whose direction were prepared the countless maps upon which the British armies fought their way to victory. It was this same geographic section which also prepared many of the maps used at the Peace Conference. In the various branches of the Department of Military Intelligence professional historians, geographers, and other experts, commissioned as officers of the General Staff, were busy throughout the war studying frontier and other geographical problems; and at the Peace Conference they contributed their part to the making of the treaties. Among the younger geographers well known to Americans was Captain A. S. Ogilvie, who was recalled from the Balkans where he had utilized his special training in making new maps for the military forces, to become an active participant at Paris in the geographical work of delimiting the new frontiers of Europe.

The Royal Geographical Society, always more closely in touch with its Government than is commonly the case with the geographical societies of America, set for itself tasks of no small magnitude. Thus under the direction of its President, Sir Thomas Holdich, the Society undertook the preparation of a topographic map of Europe and the Near East on a scale of 1:1,000,000, a similar map* of Africa on a scale of 1:2,000,000 and a map of Asia on a scale of 1:5,000,000. These maps were designed for various uses by the War Office, and for certain of the peace conference work. For the Foreign Office the

Society also issued a series of wall maps showing "Historical Boundaries in Europe," using grouped sheets of the 1:1,000,000 map as a base, and showing successive boundaries in different colors. These boundaries were drawn with great care, on the basis of extended research, and represented a valuable contribution to the work of preparing for the peace discussions. These are not all, but merely important examples of the activities of the Royal Geographical Society in the service of its country.

If one left London and crossed the Channel to the British front in France, seeking evidence that the science of geography was doing its share in war work, he was not disappointed. From the general headquarters of the British Expeditionary Force, down through the separate Army Corps and lesser headquarters, to the most humble artillery observation post, he found everywhere overwhelming testimony that an army fights on its maps, just as truly as on its stomach. Maps of many types, of many scales, in many colors, showing every variety of information and used for every conceivable purpose, tens of thousands, hundreds of thousands of maps — such was the contribution of the topographer and cartographer to the winning of the war. Not least among the serious consequences of a big German advance was the fact that it pushed the Allied armies off of areas accurately mapped on large scales, and into back areas where only smaller scales and less accurate maps were available. This not only imposed on the engineers and the geographical sections of the staffs a heavy burden of work at a critical time, but made less effective artillery fire on the German back areas, since the enemy also had moved into regions for which the Allies possessed no accurate large-scale maps. In many cases maps carried information of such high value that it was forbidden to take them into the front-line trenches, lest an unexpected enemy raid should give them into the possession of the Germans; and the capture of similar maps from the Germans was always a happy event.

To supplement the representation of the earth's surface by maps, and to render more realistic the forms of the hills and

valleys, relief models were employed in large numbers. Field Marshal Sir Douglas Haig, when asked some question on a geographical point, drew from a chest a small-scale relief model of the battle front and with its aid elucidated his answers. Before some of the most important engagements, a large-scale relief model of the battle area was constructed, and officers rehearsed the coming attack while studying this miniature representation of every hill, valley, knoll, and ravine which they would have to cross. No class in the geographical laboratory ever gathered around geographical models with such breathless interest as did those British officers who studied in this way the slopes of Messines and Vimy Ridges; for to them to know the detailed geography of those critical areas was literally a matter of life and death.

Weather prediction became a subject of constantly increasing importance as the war progressed. Battle plans depended upon possible weather changes, and a knowledge of the conditions of the higher layers of the atmosphere was more and more imperative as the flying forces grew in size and increased the scope of their activities. When the use of poison gases developed, wind direction and possible wind changes assumed a new significance. Weather conditions at sea must be known in advance to direct properly the marine flying corps and the operations of the fleets engaged in combatting the submarine menace. It was not surprising, therefore, to find at the front, in the flying camps and along the sea coast large numbers of meteorologists, experts on the physical geography of the air, placing their special knowledge at the service of army and navy.

Were the French equally alive to the importance of geography in the war? Did their admirable army organization provide place for a staff of geographical experts? Let us visit Paris first, then the army fronts, to find answers to these questions.

Leave the Place de la Concorde, cross the Seine, and pass by the Chamber of Deputies. When you reach the Rue de Grenelle, turn to your right. A big auto-camion driven by a

French soldier is just emerging from the unpretentious archway of No. 140. You note that the camion is filled with great bundles of what may be maps, so you enter the archway and find yourself in an open court, surrounded by a series of low buildings, some of them mere temporary structures. This is the headquarters of the Service Géographique de l'Armée. In a small office at the head of a dark stairway you would have found all through the anxious months when the decision of arms hung in the balance, the distinguished figure of the chief of the service, General Bourgeois. Under his efficient direction the science of geography was standing behind the blue-coated man behind the gun.

Had you inquired into the organization of the Service you would have discovered that it included a section of Geodesy (in which little or no geodetic work was then being done), and an affiliated section which directed the highly important work of determining the precise geographic location of enemy guns by triangulating, with special instruments, for the position of their flashes and for the points of origin of the sound of their explosions. Another section was charged with topographic surveying along the front, for in the midst of the war new maps, including one series on the large scale of nearly 6 inches to the mile, were being prepared for portions of the front. The general impression that no detailed mapping for military purposes would be necessary in a country so well mapped as France, is not correct. Although a part of the front had been mapped on a scale of 1:50,000 before the war, and contour maps on a scale of 1:20,000 had since been made for the whole front partly on the basis of new surveys and partly by enlarging and adapting smaller scale maps of earlier date, the German advances forced the line back into territory for which the best topographic data available was that used in preparing the old 1:80,000 État Major hachure sheets. When these were enlarged to the 1:50,000 and 1:20,000 scale, and printed with a grille for control of artillery fire, it was found that they were so inaccurate as materially to impair the effec-

tiveness of artillery operations. It was, therefore, necessary to make new surveys back of the front, and up to the limit of observation of the terrain held by the enemy, in order that both at that time and in case of a future enemy advance the enemy would be on ground of which the Allies should possess accurate maps.

The section of Cartography, with its subsections on Drawing, Photography, Engraving, and Printing, handled the gigantic task of publishing the incredible quantities of maps needed by every branch of the French and Allied armies; for the Service Géographique served not merely the needs of its own armies, but placed its facilities at the disposal of its Allies whenever this would contribute to the success of the common end. The magnitude of the cartographic work performed by the Service Géographique could only be appreciated by one who saw day after day, great auto-trucks being loaded with maps to be despatched to the various army headquarters. Map printing establishments throughout the country were commandeered by the army, and it was practically impossible at that time to get a map printed anywhere in France without an army order. All of this work was, of course, in addition to the large number of maps of all kinds prepared and printed by the different army headquarters at the front.

Maps of foreign countries were purchased or reproduced under direction of the section of "Cartographie Etrangère." In addition there was a section to handle the geographic equipment (field glasses, surveying instruments, instruments required in the artillery service, etc.), a Printing Section, a section to prepare geographic monographs of countries where the Allied armies might operate, and a section to construct relief models of all the battle fronts. Those who have imagined that the fighting forces of our Allies paid little heed to the geographer and his science, may well stand amazed at the scope of the organization of the French Service Géographique.

Across the street from the main headquarters of the Service was an ordinary French apartment house of the older type,

and up its four flights of rickety, winding stairs, was a door bearing a small cardboard sign, "Commission de Géographie." The key was usually in the lock, and one might enter at will, to find two small, bare rooms, containing less furniture and more brains than one would ordinarily expect to find in a government bureau. Bending over small tables heaped high with maps and books were the men who have made French geography known to the world: Emanuel de Martonne, son-in-law of Vidal de la Blache and Professor of Physical Geography at the University of Paris; Antoine Vacher, Professor of Geography at the University of Lille; Lucien Gallois, editor of the *Annales de Géographie* as well as Professor at the Sorbonne; Albert Demangeon, also of the Sorbonne where he has charge of the work in Human Geography. Assisted by other geographers of note and by some of their students in uniform, these men constituted the section of the Service Géographique known as the "Commission de Géographie," and labored day and night to prepare for the French Army a series of confidential geographical reports for all areas where military operations might become necessary, and for all of the enemy countries.

The actual work of studying maps and reports, assembling data, and writing the monograms was performed by the men whose names have been given; while much of the labor of compiling statistics, preparing maps, and similar duties fell to the soldier assistants. The members of the Commission were guided in their work by general specifications laid down by the army authorities and of course provided whatever information these authorities requested. On the other hand, the army authorities wisely refrained from setting arbitrary limits and iron-clad standards to which the reports should conform, but left some discretion to the experts engaged in the actual assembling and preparation of data.

It would be improper to record all the uses made of the geographical reports issued by the Commission de Géographie; but their practical value was abundantly attested by requests

for additional data and demands for new editions. It needs no special insight to understand that a complete description of the railway system of a country might enable an intelligence officer to interpret isolated reports from spies in that country regarding troop trains observed by them at different points, and thus to construct an accurate picture of enemy troop movements then taking place. The value to airplane bombing squadrons of geographic descriptions of the vital economic points in enemy territory, is manifest. The reader may himself imagine many other advantages which a full geographic knowledge of enemy territory would give to army commanders.

But the preparation of geographic monographs by no means measures the full service which the Commission de Géographie rendered during the war. High officers of the army appealed to it for geographical information on a variety of problems. Prior to the Aisne offensive they asked the Commission for detailed data regarding the character of the river and its valley floor, the nature of the soil, number of bridges, possible locations for new bridges and the nature of the river banks at such localities. They also required a special report on the quarries occupied by the Germans, their depth, best ways of entering them, and particularly which ones of the underground quarries were provided with a surface covering of a thickness and quality which would enable heavy artillery to crush in the roofs by bombardment. On another occasion they asked for a report on the Roumanian and Russian fronts as regards conditions of marshes, rivers, soil, and roads, in the spring of the year, in order that the high command might determine the advisability of a great spring offensive. In these and many other ways the Commission de Géographie of the Service Géographique contributed valuable aid to the prosecution of the war.

If it be true that an army fights on its maps, it is also true that during the latter part of the war the Allies fought on geographic models. The section of the Service Géographique

charged with the task of supplying the armies with large-scale relief models of the whole front was in itself an impressive organization. A visitor whose credentials admitted him to the upper floor of the Invalides found that a portion of the galleries had been transformed into a great laboratory where highly skilled men and women were busily engaged in making plaster reliefs with a speed and with a degree of precision never dreamed of by the ordinary maker of geographic models. Speed was essential, for military operations of the highest importance might be awaiting the completion of the models in order that every detail of the battle area could be studied on a miniature reproduction of the original surface. Accuracy was no less essential, for the slopes of the land as shown on the models were often used to determine the trajectories of gunfire, and hence the kind of artillery necessary to reach certain concealed areas behind hills or mountains; and also to determine quickly and accurately what areas of enemy territory were invisible from any observation post within the Allied lines, and where accordingly the Germans most probably would have depots of importance. The skill developed by the staff of women trained to superimpose on the completed model a tissue paper map of the same scale showing every detail of military value, and to stretch and warp this paper till it adhered to the hills and valleys of the plaster relief without displacing stream lines from the valley bottoms or hill crests from the high points of the model, was most amazing. So perfect was the machinery of this organization and so skilled were its employees, that if an army commander telegraphed one morning that he required a relief model of part of his battle front based on a map covering, let us say, 30 to 40 square miles on a scale of 3 inches to the mile, the completed model could be shipped to him the evening of the next day, and forty or more additional copies by the following evening. If the terrain was unusually rough an additional day would be required for the first model. Those accustomed to regard the construction of such models as a matter of weeks, will fully appreciate what this

high development of the art of model making must have meant to the Allied armies.

One who watched the large number of models under construction at the Invalides, or saw them piled high in their corrugated pasteboard box containers in the store rooms, or observed the many camions loaded with the large wooden cases in which they were shipped to the front, gained an impressive idea of the magnitude of this geographic contribution to the war. The impression was greatly heightened when he learned that the Invalides contained only one of the several establishments in Paris devoted to this important work, and that at various headquarters along the front were still other laboratories busy at the task of making relief models.

While Paris was indeed the center of the geographic work of the French Armies, the visitor to army headquarters at the front also received a vivid conception of the rôle played by certain phases of geography in the military operations. It was, for example, a surprise to note the excellence of the equipment for drawing, engraving, and printing maps which one found only a few miles back of the fighting zone; and a matter of the greatest interest to observe the methods by which airplane observations and photographs, reports of scouts and raiding parties, data captured from prisoners and secured by spies, were systematically being incorporated in new maps of constantly increasing accuracy and detail. It was a surprise, too, to see the size and equipment of the relief model laboratories at certain headquarters, and to learn the practical military uses to which these representations of the earth's surface were put. And it was during the terrific artillery duel which accompanied the second battle of the Marne that a French major explained to me a new geographical instrument he was perfecting to improve the method of making contour maps of enemy territory from airplane observations. In the study of air currents and in weather forecasting the French meteorological service was likewise active along the entire battle front.

The French officer devotes a part of his training period to

the study of military geography, and while the subject does not appear to be adequately treated, I found among French officers in general a lively respect for geographical science and for its value as a military weapon. General de Castelnau, whose genius saved eastern France at a critical moment in the early days of the war, manifested a profound knowledge of the topographic details of the *cuestas* and lowlands of the Nancy region when he explained with the aid of maps how he reversed the traditional theory of French military writers that Nancy could not effectively be defended, and demonstrated that the peculiar topography of that area made it possible for an inferior number of French troops to defeat the attacks of superior enemy forces. General Hirshauer, with the relief models of the Verdun district before him, gave me a clear and accurate account of the river captures in the Meuse basin which caused the peculiar features of the valley in which the fortress city is located. General Le Rond, of General Foch's staff, was selected as the French expert on military and frontier geography at the Peace Conference.

It is not necessary to trace in detail the uses made of geography in all the Allied armies. In Italy the map-making equipment was of a high order, and both in the Military Geographical Institute at Florence, under the direction of General Gliamas, and at the General Army Headquarters near Padua, beautiful cartographic work on a great scale was carried on. The Italian photographic section far excelled the best work of the other Allied armies in the scope and excellence of its product. Italian soldiers were sent to the Paris laboratories to learn of the French their methods of making relief models, and later constructed a complete series of large-scale models for all northern Italy and the east Adriatic Coast. Colonel de Ambrosis of the Italian General Staff, a professor in the Military Geographical Institute at Florence where he had, before the war, begun the publication of reports on the physiographic provinces of Italy especially adapted to the needs of army officers, accompanied me along the Italian front

and discussed at length the geographical problems confronting Italy's armies, and the geographical problems which would confront her statesmen when the time should come to delimit Italy's new frontiers. As an instructor of army officers Colonel De Ambrosis gives courses on geology and geography, and requires field excursions in order to insure a practical understanding of the value of these subjects to the military man.

On the Balkan front, where facilities were certainly very inferior as compared with those to be found in England, France, and Italy, one nevertheless found that map-making establishments, relief model laboratories, and other geographical equipment were among the things considered indispensable. The lack of good maps for the Balkans imposed upon the engineers, geographers and cartographers an unusually heavy burden, particularly as the enemy's territory had to be mapped in large part by means of airplane observations.

The fact that America entered the war very late, and depended upon her allies, particularly France, for much of her needed geographical material, makes impossible any comparison between geographical work in the American and Allied armies. We may, however, note some of the ways in which geographical science contributed to America's share in the war. Our leading geographer, William Morris Davis, prepared for the use of our army officers, with the approval of the Geography Committee of the National Research Council, a "Handbook of Northern France" which had a wide distribution, and later undertook a similar work on Western Germany. The Division of Geology and Geography of the Council issued for army use a special edition of that part of the present writer's "Topography and Strategy in the War" which dealt with the western front.

To assist in the work of the Student Army Training Corps, the Division of Geology and Geography prepared and issued under the editorship of Herbert E. Gregory, a "Textbook on Military Geology and Topography," an "Introductory Meteorology," and a "Syllabus on the Geography of Europe." The

Division was also instrumental in stimulating the preparation and publication of several pamphlets describing the physical features of the environment of some of the army training camps. These reports, generally issued by the State Geological Survey, emphasized the topographic features of military significance, the physiography and its influence on the economic development of the region described.

The Division was also active in collecting important information on a variety of subjects of military importance which it supplied to the interested Government Departments. Most of the information was of a geological nature, but in its treatment it was somewhat geographical.

American geographers were called upon to serve the Government in the War Trade Board and other organizations, and a number were commissioned as officers in the army, some for service at Washington and others for service abroad. Two were assigned by the War Department to make detailed geographical studies along the western and Italian fronts, and one of these was also sent to the Balkans on a similar mission. American meteorologists were commissioned as officers and sent to France to contribute their aid to our military operations. The "Inquiry" organized during the war under the direction of Colonel House, and directed by the President to make preparations for the coming Peace Conference, had its headquarters in the building of the American Geographical Society at New York, employed the map collections and map making facilities of the Society in its work, had the Director of the Society, Dr. Bowman, as its executive secretary, and enrolled other geographers on its staff of experts. The first troops to leave for Europe took with them collections of detailed maps provided by this same Society. These are but examples of the many ways in which geography came to the aid of the American Government in solving problems arising from the war.

As an aid in preparing for some of the problems of the Peace Conference the "Inquiry" undertook the preparation of

large block diagrams of certain territories which it was expected would be the subject of negotiation at the close of hostilities. These block diagrams are with little doubt the most detailed and exact ever prepared for any purpose. They cover the region of northeastern France including Alsace-Lorraine, the Trentino, the Isonzo-Istria area involved in the Adriatic dispute, Albania, and a large part of the Balkan peninsula. Copies were distributed to commanders in our own and the Allied armies, and served a useful purpose in enabling officers to get a clear mental picture of the salient features of the terrain on which they were operating. Inspired by these diagrams, Dr. Kirk Bryan, a geologist serving in the American Expeditionary Force, prepared a more detailed block diagram of the Argonne Forest region, which was distributed to officers with an annexed explanatory description, as part of one of the orders issued during the Argonne campaign. Thus the geographical diagrams designed especially to elucidate problems of the peace were found to have a practical value in prosecuting the war.

The Peace Conference was one of the necessary consequences of the war; and no account of the rôle of geography in the world conflict would be complete which did not place upon record the immense service rendered by geography in the task of remaking the map of the world. Every delegation to the conference included geographical experts, and there gathered about the green table in different commissions and sub-commissions De Martonne of France, Ogilvie of England, Cvijic of Serbia, Romer of Poland, Bowman, Jefferson and Johnson of America, and others from other countries. On certain of the International Territorial Commissions constituted by the Great Powers to draw the new frontiers of Europe, the Secretary of State named American geographers to represent the United States and to sit with diplomats of the stamp of Tardieu, Jules Cambon, and Sir Eyre Crowe. President Wilson and the Commissioners frequently asked and acted upon geographical advice in regard to the more difficult territorial

problems of the peace settlement; and during certain periods when these problems were actively under discussion, one of the geographers would have daily morning conferences with the Commissioners to discuss matters which would be debated in the Supreme Council in the afternoon. At meetings of the Supreme Council, of the Council of Ministers, and of those Territorial commissions which did not already contain an American geographer on their membership, one of our geographers was usually present as consulting expert when territorial questions were on the *agenda*.

The American delegation included in its organization a Division of Geography charged with the highly important task of supplying to the President and Commissioners not only copies of published maps of every variety needed in their deliberations, but in addition a never-ending series of new maps to illustrate special problems and the recommendations of the staff of experts; and a Division of Boundary Geography which scrutinized proposed new frontiers to determine whether they were in harmony with the geographical conditions in the regions affected, and to suggest such changes as topographic features, economic relations, trade routes, lines of communication, and other geographic elements might render advisable. Before a boundary delimitation was written into a Treaty, its every detail was passed upon by a geographical sub-commission. There is therefore some reason for hoping that the execution of the new treaties will not be hampered by the discovery of such geographical blunders as diplomats have frequently perpetrated in past peace conferences.

The map-making establishments set up at Paris by certain of the delegations bore witness to the importance attributed to the cartographic work of the Conference. The facilities of the Service Géographique were already at hand. In one end of the Bois de Boulogne the British erected at great expense a first-class establishment for the drafting and engraving of maps of various types, and among other things handled part of the work of printing the large-scale and small-scale maps

showing detailed locations of tentative boundaries which formed the basis of discussion in the Supreme Council. Less pretentious but very effective was the equipment for reproducing by photostat and other processes the large quantity of special maps demanded by the American delegation. In like manner other delegations had the cartographic equipment best adapted to their special needs. Any style of map needed at the conference could be produced on short notice, if not by one delegation, then by another. In order that the American delegation might have at its disposal the latest geographical material produced in neutral and enemy countries, Major Lawrence Martin was sent on a special mission to various parts of central Europe, and through his efforts new maps were constantly being added to the collections in the Hotel Crillon.

The importance of relief models in military operations has already been emphasized. Believing that such models would prove of inestimable value in the peace negotiations, the present writer submitted, before the close of the war, a project for the manufacture of large-scale relief models of every territory likely to be in dispute at the Conference. Details of the plan were worked out in collaboration with the French geographer, De Martonne, and submitted to General Bourgeois of the Service Géographique, who gave his hearty approval and support. The French Government adopted the project, and work began at once with American and Italian coöperation. Before the tremendous task could be completed hostilities ceased, but the work continued during the sessions of the Conference. Full series were in time available for the west bank of the Rhine, the Saar Basin, the Belgian frontier, the northern Italian frontier region, the Julian Alps and Istria, and the east Adriatic coast; and large areas of Albania, Bohemia, and certain other districts were completed in time to be of real service. In the large rooms set apart for maps and models at the Hotel Crillon the American Commissioners studied frontier questions on facsimile reproductions of the real topography of disputed territories. Groups of the models were occasionally transferred

to the Quai d'Orsay when a difficult question needed elucidation in commission. Two sets covering critical points in the Adriatic controversy were set up in the study of the President's mansion in Paris, in order that he might make constant use of them in his negotiations over that thorny question. In these and other ways the geographic models served the statesmen of the world on many occasions.

These pages make no pretense at cataloguing all the uses of geography in the peace negotiations; rather they aim merely to give the reader some conception of the scope and variety of that usefulness. Certainly no other peace conference in the world's history ever witnessed such an effort on the part of the negotiators to make their territorial decisions geographically sound. And while political considerations sometimes overthrew both science and common sense, when the true inside story of the conference is written it will be found that the territorial experts had much to say about the location of Europe's new boundaries; and that in making peace, as in making war, the science of geography played a most important rôle.

XII

CONTRIBUTIONS OF GEOLOGY

DOUGLAS W. JOHNSON

IT was at dinner at the mess of General X. During a pause in the lively conversation carried on by the members of his staff, I casually asked the General himself a question which I had propounded many times before under similar circumstances:

“Have you found any practical use for geological information or assistance in the course of your operations?”

On previous occasions the answers had varied from an emphatic “yes,” with concrete illustrations of the practical uses made of the science in solving military problems, to an equally emphatic “no,” with reasons why geology could not be useful in warfare. One general naïvely explained that trenches and dugouts reached but a moderate depth below the surface, and that as geology only dealt with deep-seated rocks it could of course not come into play in military operations.

This evening my host replied by telling the following story:

“We had to establish a big aviation camp at Y, and I sent an officer who is a trained geologist to report on the matter of water supply. After a careful examination he reported that for the number of men to be assigned to that camp, so many wells must be dug to assure adequate quantities of water throughout the entire year. This report was sent to the commanding officer of the camp for his information and appropriate action. It soon came back with the endorsement: ‘What is the use of digging wells in a country which is already saturated with water?’

"The report was filed away. Summer came, the surface water disappeared, springs gradually diminished in volume, and the small number of previously existing wells could not begin to supply the demands made upon them. Then we got a distress call from the commanding officer: 'For Heaven's sake come dig us some wells. We have no water.' Now my geological officer got his revenge. He sent a reply which read something like this:

" 'Referring to your request of even date that some wells be sunk in your camp, your attention is respectfully called to my report of February —, specifying the number of wells you would need, and to your endorsement of said report to the effect that there was no use in digging wells in a country already saturated with water. I regret to report that all our drilling parties are at present engaged on pressing work duly authorized; but as soon as a party is free, it will be sent immediately to your assistance.'

"Since that day," concluded the General, "no one in this army thinks of doing anything in a new region without first consulting our geologist."

Not in all armies did the geologist enjoy such high confidence. A survey of the army fronts, even in the last days of the war, would have shown that in some localities and in some problems geological science was actively contributing to the prosecution of military operations; while in others the geologist was conspicuous by his absence, and the most heard about him was a number of complaints from engineers and officers that their work was seriously hampered because of the lack of geological information and assistance. Nevertheless, the sum total of the contributions made by geology toward winning the war is a creditable record, and the reader may be interested in some examples of the many ways in which a knowledge of the earth's crust was made to increase the effectiveness of the military campaigns.

In England one naturally turned first to the headquarters of the Geological Survey of Great Britain, in London, to learn

whether the Government's official geologists had been called upon to contribute their special knowledge to the solution of military problems. Inquiry developed the fact that a great range of geological questions had been submitted by the military authorities, and that the members of the Survey, both in the office and at the front, were busy finding the necessary answers. When German "pill-boxes" were captured, the Survey was asked to determine the source of the gravel used in the concrete with which they were constructed, for thereon hung an important question as to how effectively a certain country was preserving its neutrality. The geologist was able to identify, in the concrete, material which could have come only from the Rhine Valley by canals across neutral territory, and thus to refute the contention that the gravel was of Belgium origin. In the same way the geologist was asked to discover the origin of certain cements used by the Germans. When between 3000 and 4000 soldiers had been rendered unfit for service by septic sores which developed on the arms of men tunneling through a particular geological formation, the Survey geologists were called upon to ascertain the cause; and they found that clay in the formation acted like Fuller's earth in removing the natural oils from the skin, with the result that the skin dried and cracked abnormally, rendering infection easy in the unclean life of the trenches. The low plain of Flanders is lacking in material suitable for road-making, so the military authorities turned to the Survey for information as to the nearest supplies of stone which, when crushed, would make good road metal. To detect and forestall German tunneling operations, some one conceived the idea of using seismographs to locate the origin of distant underground blasting, and the testing of this idea was turned over to the Survey authorities as the ones most familiar with the use of earthquake recording instruments.

The medical department of the army required information as to the geological formations likely to yield good water supply in large quantities, not only in France and Belgium, but

also in half a hundred or more places in Great Britain where large bodies of men were quartered in training camps and hospitals. The army engineers wanted to know the value of certain sands for use in concrete, why particular formations squeezed out into the trenches and dugouts, about the use of sandscreens in wells, what was the permanent level of underground water in many localities, and a long list of additional things equally varied. War trade organizations wanted information on mineral resources in many parts of the world. The navy desired help in testing various minerals needed for the manufacture of instruments used in important submarine devices, in locating coal supplies in distant ports of the world, and in finding suitable water supplies for a large number of naval stations. The ministry of munitions asked about caves for storing high explosives, and the sources and quality of minerals used in the manufacture of such explosives. Even the air service had its geological problems to bring to the Survey officials. All these needs, and many more which lack of space forbids us to mention, were met by the trained staff of the Geological Survey of Great Britain. If this were the whole story, surely few would deny that this scientific branch of the British Government had amply justified its existence when the test of war came.

But it is not the whole story. Some members of the staff were missing for a time, and inquiry would have elicited the information that three of them were in the Gallipoli peninsula developing a water supply for the forces engaged in that ill-fated campaign; while others were here or there on other geological missions. At the front you might have found Belgian, British and French army officials eagerly consulting one of the only two known available copies of a detailed geological map of Belgium showing geological cross-sections and well records of most vital importance, both copies having been supplied from the files of the British Survey. On asking about the other copy, you would have learned that the Survey staff was busy preparing from it as a base, a new issue for distribu-

tion among the many headquarters where it was urgently needed. And had you seen the great mine explosions at Messines Ridge, the greatest of the entire war, and had asked where the vast tunneling operations were planned which made possible that remarkable series of nineteen volcanic eruptions, the reply would have been, "In the offices of the Geological Survey in Jermyn Street, London." From every part of Britain's far-flung battle front were threads running back to converge at the offices of the Geological Survey.

The most effective use of geology in warfare requires that a competent geological staff shall be located in the active theater of military operations, where it can quickly examine and constantly supervise every geological problem which may arise. Our British friends were alive to this truth, and established at their General Headquarters in France a geologic corps, attached for convenience to the section of the Chief Engineers. The Chief Geologist was Lt. Col. T. Edgeworth David, the distinguished Australian scientist who accompanied Shackleton on one of the Antarctic expeditions; and associated with him were Captain W. B. R. King of the British Geological Survey, and several other assistants. Their office formed part of the Headquarters establishment, but their active labors extended the full length of the British front in France and Belgium.

It would not be possible, even were it desirable, to present in a single short chapter any adequate account of the variety of geological services rendered by Col. David and his co-workers. Suffice it then to mention the principal divisions into which those services may conveniently be grouped, and to give some examples under each. Let us turn first to the all-important matter of locating underground mines, tunnels, and dug-outs. It was fortunate that the British General Staff included generals who held the opinion that geological study was absolutely essential to the proper location of these underground workings, and who were frank enough to express their regret that geologists had not been employed from the

moment the opposing forces began "digging in." At least two such generals were among Col. David's superiors at Headquarters, and the success he was able to achieve in the practical application of engineering geology to military projects was no doubt partly due to the breadth of vision of men of this stamp. One of these generals admitted that in the beginning army officials were as a rule very skeptical as to the practical importance of Col. David's geological theories. But, he added, after several bad blunders due to refusal to take geological advice, and several striking demonstrations of Col. David's ability to predict accurately the conditions which would be encountered in depth by underground workings, they were so far convinced that before the end of the war no responsible officer in the British Army would consider the planning of such works without first securing the opinion of a geological expert.

The non-geological reader will have no difficulty in understanding the importance of geological aid in selecting locations for excavating mines, tunnels and dugouts, if he will remember that some rocks are porous and permit the ready passage of water, whereas others are more or less impervious. Now it happens that along part of the front one rock formation, through which comparatively little water circulated, had both above and below it layers carrying great quantities of water. If the army engineers kept their tunnels or other excavations well within the non-saturated bed, all went well. But as soon as they got too high or too low, water burst through from the adjacent formations and flooded their works. Only a geologist familiar with every detail of each formation could guide the underground work so that it would be sure not to end in disaster. At Messines Ridge, where precisely these rock conditions existed, very careful geological examinations were made on the ground, in addition to work done at the Geological Survey office in London. Thus the most extensive military mining operations in all history were undertaken on the basis of geological study. That they were successful

despite the dangers from waters both above and below, is sufficient evidence of the excellent work done by Col. David and his staff.

Practically all rocks below a certain variable level known as "the groundwater level," contain water so that tunnels, dugouts or other excavations which go below that level will be flooded. Hence it is necessary to know the distance from the surface of the earth down to groundwater level all along a battle front, and an important part of the work of the British geologists was to prepare detailed maps showing just how deep at any given place excavations could safely be carried, or how deep wells would have to be driven to get plenty of water. In the rainy season the groundwater level begins to rise, and as the change takes place slowly there is a "lag," or the rising continues for a time after the rains have ceased. An engineer who drove a tunnel just above the groundwater level at the end of the rainy season might well suppose that he was quite safe, and yet have the tunnel flooded by a further rise of the groundwater. Precisely this happened to a number of German tunnels. Thanks to the skilful work of Col. David the British were saved this misfortune; for Col. David determined not merely the groundwater level for a given time, but the *variations* of the groundwater level as well; and constructed curves showing just how high the level would be at every time of the year. He then directed the army engineers how to locate their excavations so that they would never be flooded; and British efficiency once more scored against the much vaunted German efficiency.

But it was not merely in locating excavations that the British geologists served their armies. They told the engineers in advance what kind of rocks they would have to pass through underground, and hence what kinds of tools and how much timbering they would require. They kept a number of drilling parties constantly busy making test borings to determine with precision the exact thickness of every rock formation at those places where the engineers planned underground work

of any kind. They gave to the water supply officer of each army the geological advice he was required to seek before putting down any well, and told him where, how deep, and in how great quantities he could expect to find good water. They provided these same officers with various water-supply maps and with geological cross-sections showing the conditions under which underground water occurred at all points along the front. They told where older rocks suitable for road metal protruded through the later covering deposits, and where the best rocks for concrete, cement and other purposes would be found. And since it was important to know what sources of valuable rocks and minerals the enemy had at his command, the geologist's knowledge of the rock formations and the mineral deposits of enemy countries was placed at the service of the army to provide this information.

Artillery fire produces very different effects on different types of soil and rock. One type of shell may produce the greater damage in a clay formation, another in a loamy soil, still another in limestone or chalk. The geologist was able to tell the artillery officer what kind of formation his fire was directed against, and thus to aid his judgment as to the type of fire he should employ. When a big attack is planned, it is vitally important to know just what surface conditions the troops advancing into the enemy's area will find, as plans for the advance will vary according to the kind of obstacles to be encountered. It is evident that the heavy barrage fire preceding such an attack must profoundly alter the surface of the country to be passed over, and that the nature of the alteration will depend upon the kind of soil or rock beneath the surface. The shell craters may be large and deep in some formations, shallow but broad in others, in still others imperfectly developed. In one formation water will accumulate in the shell craters if it rains, but not otherwise; in another water will in any case be admitted because the bottoms of the craters penetrate a water-bearing bed; in yet another no water will stand in the craters no matter what the weather may be. It should

therefore be evident that maps showing the kinds of surface troops will have to cross following heavy barrage fire must be of great value to an army commander. The British geologists prepared maps of this kind for much of Belgium and northern France.

Tanks can advance over certain kinds of soil, but their great weight causes them to sink deep and become mired in others. So it became important to know in advance what were the soil conditions behind the enemy's lines. "Tank maps" were therefore produced by the geologist, showing where tanks could, and where they could not go.

Before retreating an enemy aims to destroy all the wells and springs in the country, in order that the pursuer may be as seriously handicapped as possible. For this reason the army commanders depended upon the geologists to prepare maps showing underground water supplies of enemy territory into which it was proposed to advance. These could be based in part upon published data available in the geological libraries of Allied countries, and in part upon long experience with water-bearing beds within the Allied lines which were known to extend under enemy territory. It was found possible from published maps of enemy areas to construct geological cross-sections of the country behind his lines, locate on these sections the water-bearing horizons, and then by making allowance for the surface topography, to prepare in advance maps which indicated with reasonable accuracy just how deep the advancing armies must sink wells in any given locality in order to get the fresh water supplies they would require.

Enough has been said to give the reader some impression of the wide range of service performed by the geologists attached to the British Expeditionary Force in France and Belgium. I think it is fair to say that in no other Allied army was geological science so largely and so successfully employed. If we turn to the record of the French Army, it does not appear that the services of their geologists were utilized to any great extent, although a limited amount of geological work

was done along the French front. One series of maps containing "General Information" carried overprints in colors showing areas of resistant rock, sand soil, regions marshy in wet seasons, regions permanently marshy, and other similar data as to surface conditions. But these maps were imperfect, and were not highly regarded by French geologists.

At certain of the French Army Headquarters in the field there were prepared and published real geological maps especially adapted to the needs of the army. Some of these maps were made by trained geologists who happened to be in some military service at the front, and secured appointment to do a little geological work. Such maps were of course well made. Others were prepared by men with little or no geological training, and quite naturally were full of errors. Those of the better grade, for example one of the region about Rheims, were well printed in a variety of colors, and were based on the standard geologic map of France. The descriptions of the formations were in terms of military importance, and the color scheme was altered so as best to portray data of this type in the special locality concerned. Whether the soil was thin and the rock resistant, or the soil deep and the rock decomposed; whether the terrain was sandy, clayey, or marshy; whether it was or was not adapted to trenches, dugouts, and other excavations; and whether such structures would remain long in good condition or require constant repairs, were among the items emphasized. Two separate columns were employed to give the special characteristics of each formation, the one in wet seasons, the other in dry seasons. A series of such maps for the whole front would have been of inestimable value to the French armies.

Excellent use was indeed made of the standard French geologic sheets by some of the engineering officers, who kept files of these sheets at the front for constant reference. One of these officers explained in detail how helpful the maps had been in guiding him to horizons best adapted for tunneling, and other underground works, and to formations valuable for road

metal and materials for concrete. Although he had no special geologic knowledge himself, he fully appreciated the importance of the maps. At the same time he added that the services of a geologist would have been most valuable to him. The maps available were very generalized, the locations of contacts were not sufficiently accurate for his needs, and the formations were not sufficiently subdivided. He needed for the sector covered by his defense engineering works a larger scale geologic map which would show accurately the distribution of each formation important from the engineering standpoint. Because of the lack of such a map he had been compelled to do a large amount of exploratory work, uncovering outcrops and studying the formations himself until he was sure he had located the proper horizon for a given purpose. All this had cost valuable time, and he felt that it was unfortunate to have French geologists mobilized for routine military occupations when their special abilities might have been utilized to save time and energy in important military undertakings.

Many concrete examples could be cited of the unfortunate consequences resulting from failure to seek geological advice. For sake of illustration I select one from the region of Verdun. At the Côte du Poivre a position was being organized on the back slope of the ridge. The officer in command ordered the construction of dugouts for protection from artillery fire at certain points, basing the selection of these points purely on tactical grounds and without regard to the geological structure of the district. After much loss of valuable time it was found quite impossible to make dugouts suitable for human occupation in the places selected, because of the great volumes of water encountered. The points chosen were located on a water-bearing horizon. Only 150 yards distant, and in positions equally good from the tactical point of view, the dugouts could have been excavated in a dry, impervious formation. Ignorance of the very simple geological structure of the dissected plateau was responsible for the commission

of an error under circumstances when errors meant loss of human lives.

As in the case of the French Army, so in most of the other Allied armies geological maps and geological knowledge were utilized locally, sometimes on a very considerable scale, but without any such systematic development of the work as took place in the British Expeditionary Force. On the Italian front I was informed that General Porro, Chief of Staff to General Cadorna, was especially interested in the relation of geological science to military problems, and that he made much use of geology in connection with the important engineering projects undertaken during the Italian offensives in the Trentino and Carso regions. At the time of my visit the Carso front had been lost to the enemy, and General Porro had retired with Cadorna; so it was not practicable to learn just how much geology had contributed to those great engineering works which preceded all principal attacks on the limestone plateaus beyond the Isonzo. On Mount Grappa and other strategic heights farther west the surface was undermined by a labyrinth of tunnels and galleries cut in solid rock, in the excavation of which the geologist had been called in as adviser. It was an Italian engineer with a geological training who ran the tunnel under Mount Tofana and placed the great mine which blew off the summit of that peak thus destroying a noted Austrian fortress. Geological advice was sought by the Italian Army in connection with its extensive road-building operations, its water-supply problems, and other engineering work. But there was apparently lacking any systematically organized geological corps.

At the General Headquarters of the Armies at Salonika I found an army engineer having some knowledge of geology, at work on a geological map of the peninsula for military use. This map was largely based on an earlier one by Jovan Cvijic, the well-known Serbian geologist, but contained new information secured in the course of the military operations. It was designed, however, to show sources of valuable minerals, ma-

terials for concrete, road metal, and similar economic products, and was not sufficiently detailed nor exact to guide engineering works below the surface.

In the Russian Armies it was the practice to attach to each large division of the military forces a technical corps which included at least one geologist and his assistants. There were said to be seventeen of these units with their associated geologists on the Russian front. It was the duty of the Russian geologists to advise their army engineers and other military authorities regarding the usual geological factors affecting the construction of trenches, shelters, and tunnels, the development of water supplies; and the location of materials needed for the building of roads, fortifications, and other military engineering works.

Before Roumania entered the war her government commissioned the Roumanian Geological Institute under the directorship of its excellent chief Professor L. Mrazec, to prepare a report with map on the surface and underground water resources of the Dobrudja. This work was duly completed, but the engineers of the Roumanian Army had small appreciation of the value of geology, and according to report little use was made of the important information put at their disposal. The Roumanian armies in the Dobrudja suffered greatly from lack of a proper water supply, and when the Russians entered the region the geologist associated with the Czar's troops was astonished to find on the one hand an unused report on the water resources of the region, and on the other an army suffering from lack of water through the short-sighted policy of its engineers. The Russian geologist found the work of the Geological Institute of so much value that he went to Bucharest in person to secure further details about the geology of the country in which the Russian troops were stationed. Among other problems referred to the Institute was that of designing camouflage to imitate the rock outcrops of certain sections of Roumania. But in general the geological services rendered after the country entered the war were slight,

and no geological organization in the army was affected.

America entered the war late, and while she thus had a smaller space of time in which to develop a geological service in her armies, she had on the other hand the advantages of long time for preparation and a well-equipped geological survey upon which to draw for men and material. Frankness compels one to say that she did not profit fully from these advantages. The criminal stupidity which brought us unprepared into a war which had been threatening us for many long months, necessarily had its deplorable consequences in every branch of the service. A million men might spring to arms over night, but when they got done springing they found there were no arms to spring to. In the months of feverish preparation which followed it could not be expected that among the thousands of things to be done proper provision would be made for an adequate military geological service. That could only come with time.

American energy, however, in some measure, compensated for our other shortcomings. The first contingent of officers which arrived in France to prepare for the coming armies sent back word that geologists were needed. Before the Armistice was declared America ranked next to Great Britain among the Western Allies in respect to the excellence of the geological service attached to its armies at the front, and was rapidly advancing to a leading position. Nine geologists were at that time attached to our field forces, and more had been summoned for service.

Under the able direction of Lieut. Col. Alfred H. Brooks, the American geologists took up the task of supplying our armies with much the same material and information as have already been described in earlier pages relating to the work of the British geologists. Geological maps, based in part on earlier French reports and in part on new observations, were carefully prepared and beautifully printed in colors. The accompanying descriptions of formations were not the technical and purely scientific accounts common to ordinary geological

maps, but practical descriptions of such features of each formation as were important from the military point of view. From these maps the army engineers could tell at once which formations were filled with water, which were dry and suitable for the location of dugouts, tunnels, and subways; in which the walls of trenches would remain vertical for a long time, and which would require timbering to prevent the slumping down of trench walls; which would give muddy and marshy surface, and which would yield valuable deposits of road metal and other construction materials.

Of equal importance were the different types of water supply maps, showing which formations carried ample quantities of good water; what was the depth below the surface of the groundwater level at any point; where existing wells were located; where new ones should be placed, and where springs could be sought with success; and all the needful information for those upon whose shoulders rested the heavy responsibility of providing the enormous numbers of men concentrated in the war zone with sanitary supplies of water for drinking and other purposes. There were also maps to show the different types of surface over which the advancing armies would have to pass following their offensives, and to portray other data of high military value.

It would involve needless repetition to show in detail how the American geologists proceeded to meet the same needs of their armies which the British in their earlier work had demonstrated could be met with enormous advantage to the efficiency of the military machine. Suffice it to say that the excellent work directed by Col. Brooks confirmed anew the value of geology as an adjunct to military operations, and commanded the respect and praise of our French and British associates.

Geologists were naturally much interested to know whether the great military machine which the German Government built up for their war of world conquest, was efficient enough to provide an adequate corps of geological workers for their armies. There is evidence to show that in the beginning not

even the Germans realized the value of geological knowledge as a military asset, doubtless in part because they expected an easy victory over their unprepared victims, and had no idea of having to fight much of the war underground. But they were not long in realizing and correcting their mistake, and with the usual German thoroughness they then provided a sufficient force of geologists to conduct the necessary investigations in a comprehensive manner. Captured documents indicated that from ten to fifteen geologists were assigned to each army operating on the western front. The size of their organization enabled the German geologists to meet demands for geological advice wherever they arose, and to bring out special geological maps of army corps areas on a scale of 1:25,000.

As an indication of the value attached to geological work in the German armies there is reprinted here a translation of one of several German orders relating to geological work which were captured by the Allies.

“I.A.54048 (B) 24.I.

Geological Section of the Fifth Army, Nr. 1/466

Corps Headquarters,

1-10-1917.

1. The Geologists of the Fifth Army belong to Field Survey Companies 3 and 15, and form a geological section within these Companies.

Reserve Lieutenant WEIGEL is in command of this Section.

2. For the establishment of Geological Offices the Geologists are distributed throughout the Army Area according to the subjoined summary.

3. Applications for the services of the Geologists will be made direct, and to avoid unnecessary delay should give the object of the application and the exact location of the Area to be investigated.

The Geologists deal direct with the formation of their Army Sector.

4. Applications for the service of Geologists must always be sent to the Geological Offices of the Section which is nearest to the formation which makes the application.

5. For Geological work in forward areas and on lines of communication, the formation that demands the work must provide labor and transport, and arrange for the rationing and billeting.

6. The duty of the Geologist is immediate assistance to the troops in cases where the structure of the ground and its water bearing qualities are a consideration. Geological advice is of special importance with reference to the following problems:

I. Construction of positions.

The assistance of a Geologist at the first reconnaissance of the country, before the lines are finally fixed, has proved of special value. See regulations for Trench Warfare, for all arms of the Service, I.b. Cipher 2, and Part II, Directions for the laying out of trenches, tunnelled dugouts, dugouts, etc.

(a). In case where several points are of the same tactical value, by choosing such as require the minimum expenditure of labour, time and material, and are not likely to involve landslides or inflow of water.

(b). The prediction in the case of lines already dug, as to what difficulties are likely to occur arising out of the hardness of the strata, and their water-bearing qualities.

(c). Information as to tracts in which dry dugouts are definitely impossible, or whether there is any prospect of draining them by natural means, as by drainage sumps.

(d). Testing the possibility of putting in dry tunnelled dugouts under the water-bearing strata.

(e). Advice on subways and galleries. Information as to which strata are the easiest to work, whether there is risk of landslide or inflow of water, the possibility of tunneling under water channels.

(f). A preliminary investigation with a view to the use of boring machines in mines warfare. Selection of favorable and exclusion of unfavorable strata.

(g). Information as to the best dugouts for listening posts and so forth.

(h). Opinion as to the stability of existing "subterraneans" (caves and quarries.)

(i). Inundations and drainage of areas.

II. Water Supply.

(a). Improvement of existing wells and selection of sites for new ones.

(b). Making good defects in existing springs, and the opening up of new ones.

(c). Information as to places especially suited for driving wells (wells made by percussion, Abyssinian wells.)

(d). The development of deep-seated water basins by deep bores.

(e). The ensuring of water supply for the defensive battle.

(f). Advice on construction of water conduits, the water supply of towns and camps, and of industrial and commercial establishments.

III. Winning of Raw Material.

(a). For immediate use in the field. The providing of gravel, sand, loam, clay, building stone, material for cement and plaster, road metal, railway ballast and peat, as near as possible to the places where they are to be used. The marking out of stone quarries, estimate of quantities, information about the stratification and best way of working.

(b). Providing of raw materials for supplying the needs of the army. One of the first considerations is the supply, for example, of pyrites, phosphates, copper, and, in the Balkan peninsula, of coal also, for the Directors of Military Railways.

(c). Records of the existence in more distant industrial fields of material available for meeting the requirements of munition and ordnance factories (new occurrences), abandoned mines, and their ancient mine and slag dumps.

Of chief importance are ores, rock-oil, coal, asphalt and other materials useful in the economies of war.

IV. Hygienic and Technical Problems.

(a). Advice on the location of sumps for drainage, cesspits, drainage in general, disinfecting and germicidal establishments and cemeteries from the point of view of risk of contamination of sources of water supply.

(b). The defining of drainage areas with a view to the protection of wells and springs, having due regard to the nature of the ground.

(c). Electrical problems so far as controlled by the condition of the ground with reference to earthing, erecting masts and burying cables.

(d). Advice on the locating of roads, field railways, light railways, cable tram-lines, with a view to avoiding cutting and embankment slides.

(e). Appreciation of suitable sites for dams.

V. Other Military Problems.

(a). Careful observation of the structure of the substrata (nature, solidity, water-content) for standing camps.

(b). Choice of dry substrata for munition dumps.

(c). Choice of suitable natural solid surfaces for heavy guns.

(d). Choice of spots naturally fitted for aerodromes.

7. The function of the Geologist is only advisory. It is not his province to see to the technical development of propositions by elaborating them from plans or by actual superintendence of the work.

Signed WEIGEL,
Reserve Lieutenant,

Commander of the Geological Section of the Fifth Army.

Among other documents captured from the Germans were water-supply and geological maps of various types, prepared at the front by the German geologists. Some of the maps, particularly those showing aerial geology, were very detailed, printed in colors, and accompanied by cross-sections in colors. Such maps were prepared for each army corps area, and additional detailed maps were printed for smaller areas of special importance. Both types of maps were executed with much care. Instead of being mere enlargements of the previously existing French maps (which were often old and inaccurate) both the topography and the geology were resurveyed, and the results were more accurate and detailed than the data shown on previous maps.

The German geologists endeavored to make their reports and maps as untechnical and as practically useful as possible. The descriptions of formations and explanations of structure were

carefully adapted to the needs of the military authorities, and the language used was such that persons having no geological training could make use of the information conveyed. That the German geologists served their armies well was abundantly testified to by the Allied army engineers, who repeatedly remarked the skill with which the enemy turned surface form and underground structure to his advantage in all his engineering works.

Nothing has yet been said of the highly valuable services rendered by the geologists of most if not all of the combatant nations, in connection with the great work of mobilizing all the resources of each country in support of the fighting machine. Not only on the War Trade Boards and similar organizations engaged in studying the mineral and other resources of Allied and enemy countries, was the geologist busy, but out in the field, scattered over the plains and in remote mountain valleys, in many a distant corner of the world, geological investigators might have been found seeking new deposits of the type of sand necessary for the best optical glass, of some mineral needed in a new anti-submarine device, or of some other element required in the manufacture of high explosives, poison gas, or any one of a hundred other products essential to a victorious issue from the titanic struggle. In laboratories other geologists were working day and night to test these materials and determine their fitness for various military uses. Still others were examining sites of cantonments, reporting on their water supplies, and preparing detailed studies of the geology and topography for use by those engaged in the task of training a great citizen army. At Washington the United States Geological Survey was placing its equipment, its vast stores of geological data, and its personnel at the country's service, and the Division of Geology and Geography of the National Research Council was organizing and correlating geological war work throughout the country, and keeping in direct touch with the geological needs of the army, thus acting as a clearing-house for geological information of every kind. In other capitals similar service,

sometimes well organized, sometimes sporadic and less sufficient, was being rendered through numberless channels. The whole story of geology's contribution to the waging of the world war will never be written; but enough is known to give us a realization of the fact that it was, in the aggregate, literally a monumental service.

Geology played no such rôle at the Peace Conference as did its sister science of Geography. In the very nature of the case the territorial settlements were primarily geographical problems, whereas geology merely entered into that and other groups of questions as one of many elements. Perhaps it figured most largely in the economic problems of the conference, including the problem of reparations.

Long before the Armistice geologists in different countries were engaged in collecting the data of their science which would be needed when the representatives of the Powers gathered about the green table. The French Government appointed two of its noted geologists, Emmanuel de Margerie and Lucien Cayeux, and a military officer with a geological training, to examine and report on the mineral wealth of the regions adjacent to the northeastern frontier of France, including the mining regions of Alsace-Lorraine which it was determined should be reunited to the mother-country. In London, Washington, and other capitals individual geologists and government geological bureaus were coöperating in assembling material and preparing reports and maps on a wide variety of questions. The American "Inquiry," the French "Comité d'Études," and other bodies specially constituted to provide the diplomats of their respective countries with information on the peace settlement, included geologists on their staffs or secured the coöperation of geologists in their work. When the Conference assembled at Paris, geologists, while less numerous than the geographers, were present; some of them throughout the long months of the negotiations, some for a few weeks only, when called upon to aid in the solution of some particular problem. Whether it was the Saar Coal Basin, the Teschen

mining district, the Silesian coal fields, or other such large and difficult questions; or boundary problems involving the attribution of minor deposits like the Idria mercury mines, recourse was had to the geologists attached to the delegations and to the elaborate reports and maps they had prepared, for the data needed as one element in making a fair readjustment of the world's boundaries. Geology, like Geography, made good its title to a place among those sciences which the governments of peoples can not neglect, either in war or in peace.

THE RÔLE OF ENGINEERING
IN THE WAR

XIII

ADVANCES IN SIGNALLING CONTRIBUTED DURING THE WAR

A. E. KENNELLY

THE fighting on land, in the world war, regarded from the American point of view, was waged on a battle line roughly 750 kilometers long, reaching from the coast of Belgium to the Swiss Alps. The center of this line is approximately 6500 kilometers, or nearly 4000 miles, from the War Department Building in Washington, D. C., the army administrative base. It is also approximately 7250 kilometers in a bee line, or 4500 miles, from Chicago, which may be looked upon as the center of gravity of America's supplies for her army. Consequently, America's overseas army of two million men had to join with Allied armies at a distance of more than one-third of the sea-level separation from pole to pole. It was, therefore, of the utmost importance that communication between Washington and the American Expeditionary Force should be kept at the highest point of effectiveness.

It is recorded that in January, 1815, the news of the Battle of New Orleans did not reach the capitol at Washington until two weeks after the battle had been fought. That was before the days of the electric telegraph and telephone. If such restricted conditions of communication existed to-day, it is safe to say that no such expedition as America sent to Europe could possibly have been conducted and maintained. In fact, the news of important events at the French front were, in this war, frequently delivered in Washington before the hours at which those events occurred; that is, within the five hours'

difference of time between Greenwich and Washington. In that sense, therefore, America knew of the important events of the war before the times at which they happened.

Again, in the European campaign of 1815, which precipitated the final downfall of Napoleon Bonaparte, the final battle took place on the field of Waterloo. From the top of a tower 60 meters high on that field, the visitor is shown by his guide the whole scene of tactical operations. On yonder elevation, the French Emperor sat on his famous white horse, directing, by couriers, the movements of his army. Over on this roadway, Wellington rode up and down surveying the battle, and sending verbal orders to his commanders. The battle opened early in the afternoon, and the fate of the Napoleonic empire was virtually sealed before darkness set in.

Such was the nature of the last preceding great struggle in Europe, when electrical communication did not exist, and when the first, but unsuccessful experimental electric telegraph was being tried, with frictional electricity, under discouraging conditions, in the back garden of Sir Francis Ronald's house at Hammersmith, in England.

At the battle on the European western front in which the A. E. F. participated in 1918, the American headquarters was necessarily remote from the front line — more than 200 kilometers from some parts of it. The final battle lasted about four months. Communication had to be constantly maintained by the American headquarters, not only with each division commander at the front, but also with the various reserves, depots and bases, as well as with the Allied headquarters and with the generalissimo in command of all the Allies. Moreover, communication had to be maintained by each division headquarters, not only with its most distant outposts, through brigade and regimental headquarters; but also with its observation balloons, its observation posts, airplanes and tanks. The army was, therefore, extended over a vast network chain of electric communications which ended, administratively speaking, in Washington. Those links of the chains which cross the

Atlantic Ocean were supervised by the U. S. Navy. The rest of the network was under the control of the U. S. Army Signal Corps. The duty of maintaining a complete system of electrical communication between Washington and the American Army overseas thus devolved, in large measure, on the Signal Corps. Under the pressure and stimulus of this duty, the very considerable advances in signalling which were made during the war, were largely developed in and by the Signal Corps, so that the story of that advance, from the American viewpoint, is mainly an account of signal-corps achievement.

Communication across the Atlantic was maintained mainly by cables underneath the ocean, and partly by radio, or so-called "wireless," over the ocean's surface. The transatlantic cables in service were heavily loaded. A few of them were out of service by breaks, partly due to accident and partly due to war. It was very difficult to make cable repairs in the Atlantic during the war, on account of the dearth of men and repairing ships, and also on account of the vigilance of hostile submarines. Those cables which remained intact were worked at the maximum available speed, duplex; i.e., in both directions simultaneously, without pause or interval of rest, day and night continuously throughout the year. In describing sustained and unremitting business, the beaver is a common metaphor; but the beaver is a very lame vehicle of expression for unceasing activity; because he sleeps through a fair share of each twenty-four hours. As busy as an Atlantic submarine cable during the war, would be a much more apt comparison for the antithesis to the life of the lily of the field, which toils not, neither spins.

In order to supplement the work of the cables, great improvements were made in transatlantic radio signalling, under the auspices of the navy; both as to speed and precision, especially between the naval radio station at New Brunswick, N. J., and a similar station in France. The results attained indicate that even without any new discoveries, or epoch-making inventions, the prospects of long-distance radio communication are im-

mense, and that the possible capacity for the transoceanic radio traffic of the world is nearly two hundred times as great as that in service during the war; but that is a matter for keeping the future out of the lap of idleness.

Before the war, the transatlantic cables from America landed mostly in the British Islands, a few going to France and Ger-



Figure 1
United States Army system of wires

many. One German cable was cut by the British, at sea, in the very early days of the war, and was later diverted to Canada at one end and to England at the other, while another cable of Germany was diverted to France; so that all transatlantic cable communication came exclusively under the operation of our Allies. The Germans, thus isolated electrically under the

ocean, kept up a continuous stream of official news and propaganda by radio, into the air from their powerful station at Nauen near Berlin. This continual outpouring of German bulletins continued by radio during the war, and could be read by radio stations over a considerable part of the northern hemisphere, including stations in America. Neutral peoples could receive these bulletins unchecked. In Britain, America, and the countries of their Allies, all known radio stations came under government control during the war, so that except in a few surreptitious instances, these electric waves of propaganda passed harmlessly over the heads of the peoples.

Signal Corps Telegraph and Telephone Lines Abroad. On the other side of the Atlantic, the Signal Corps, in 1917, began building and leasing a complete system of telegraph and telephone lines in France and England. The accompanying map, Fig. 1, shows the U. S. Army system of wires in those countries shortly after the Armistice and after communications had been carried forward into the occupied region of Germany. The heavy lines on the chart indicate conductors built and operated by the Signal Corps, the light lines those which were operated by the Corps, but leased from the respective Allied Governments. The system is seen to run from Brest, St. Nazaire, and Bordeaux with their environs, through Tours and Bourges to Paris, and to the American front near Toul and war-scarred Verdun. Connecting Paris with London were two separate leased lines, one crossing the channel near Boulogne, and the other by a special cable near Havre. The Signal Corps built in France about 3500 kilometers of pole line, carrying some 50,000 kilometers of copper wire. Counting 35,000 kilometers of leased wires, 120,000 kilometers more for networks of telephone wire from the various headquarters to the front, and 150,000 km. of locally erected army telephone wires, the Signal Corps wire system comprised a total of approximately 358,500 km. of wire in France and England, or nearly enough, if spliced end to end, to reach to the moon.

The traffic which this army telegraph system had to carry

was necessarily very heavy. It comprised not only all the telegraph and telephone communications between different depots and headquarters in France; but nearly all those between the army and America. It has been estimated that the telegraph system carried in all more than five million army messages before the Armistice. The average army message is much longer than the average telegram of commercial and civil peace. It may be taken as sixty words in length. This represents an average of about 10,000 telegrams or 600,000 words a day. The highest record was 47,500 telegrams or 2,850,000 words in one day.

In order to carry this heavy traffic, the wires had to be worked by specially rapid signalling methods. One of the trunk lines was from Paris to General Headquarters at Chaumont, and consisted of four parallel copper wires on poles. These wires naturally formed two pairs, say A, B and C, D. Over each pair a separate telephone circuit was arranged in the ordinary way. On these two parts an additional telephone circuit was made up of the type known as the "phantom circuit." This provided, in all, three sets of telephonic communications between Paris and Chaumont. Moreover, each of the four wires was worked as a telegraph wire without interfering with the telephonic conversations. Wire A had a synchronous three-channel multiple printing telegraph system in operation over it, permitting three messages to be sent simultaneously in each direction. Wires B, C and D were also each worked duplex, or simultaneously in opposite directions, telegraphically. As the result, twelve streams of telegrams — six each way — were obtained over these four wires, day and night, in addition to the telephonic conversations.

To operate these telegraph lines, a number of American operators were brought over to France in the Signal Corps, and a number were also trained in special schools overseas.

Telephone Service with A. E. F. While the heavy traffic of main army communications was carried on by telegraph, a vast amount of local communication was conducted by tele-

phone. This telephone service was of two kinds; namely, internal telephone service within the army itself, and external telephone service between the U. S. Army and other armies or more specifically (1) external service between the U. S. Army and officials of the French Army or civilian life, and (2) internal service within the U. S. Army organization itself. Those two services had to be handled in different ways.

The first telephone exchange for external and internal service was opened by the Signal Corps in Paris during June, 1917. It served to connect the army offices with each other, and with the French telephone system. American soldier operators had no difficulty in making internal connections; since the English language was exclusively used. When, however, connections had to be made through a French exchange, it was necessary for the operator to be familiar with the French language. In fact, he had to be skilled in the use of French, for it is one thing to be able to speak to a person face to face in a foreign language and another thing entirely to speak to him at a distance, through the medium of the telephone. Although the French people are notoriously tolerant and forbearing with foreigners attempting to speak their language, the diplomatic difficulties are enhanced when the mutilation of their language occurs over a wire. A *modus vivendi* was reached by using the relatively few French-speaking U. S. Army operators on the external switchboard calls, and by the French using their relatively few English-speaking operators on these same wires at their switchboards. At the best, however, there was a good deal of language difficulty in the external telephone service.

To cope with the language difficulty over telephone wires that had to convey both French and English speech, the Signal Corps called in the aid of the American Telephone and Telegraph Co. in the States to furnish female operators who could speak both French and English, for service with the army in France. There were hardly any such bilingual operators in the American service; so they had to be advertised for and specially trained in the States before being sent to France. It

was supposed that French Canadian provinces might furnish such persons most readily; but most of them were actually obtained from families of French descent living in the States. They responded patriotically to the call and underwent a swift and strenuous course of switchboard training in New York. They were then assigned to the Signal Corps and taken to their posts overseas in units. All were dressed in blue uniform with a telephone transmitter on the arm as insignia. They were located by groups in a number of French cities and towns. Their arrival was always followed by a marked improvement in the external telephone service. Their service, often under army conditions of discomfort and even danger, was rendered with the same courage and cheerfulness as the soldiers displayed.

The army telephone exchanges rapidly spread and multiplied as the American divisions arrived in France, until there were 273 installed at the Armistice date. This represented a very efficient army telephone system. It will be remembered that while the telegraph services of Europe have always been excellent and in some respects superior to our own, the telephone and telephonic service have from the very outset been specially well developed in America. The United States has always led the way in the extent and effectiveness of telephone service and equipment. The result of the Signal Corps telephonic system installation was an excellent system of communication behind all the American lines. It is credibly asserted that Marshal Foch, in the course of his many journeys along the Allied front, would always order his chauffeur to find the nearest American telephone exchange, when he desired to stop and talk with any of his lieutenants; because he felt he could rely on the Signal Corps not only to provide prompt service to any post, but also to keep its system patrolled against eavesdropping by enemy spies.

A portable telephone exchange at brigade headquarters is illustrated in Fig. 2. At the back of the room is a telephone desk set captured from the German army. Fig. 4 shows a

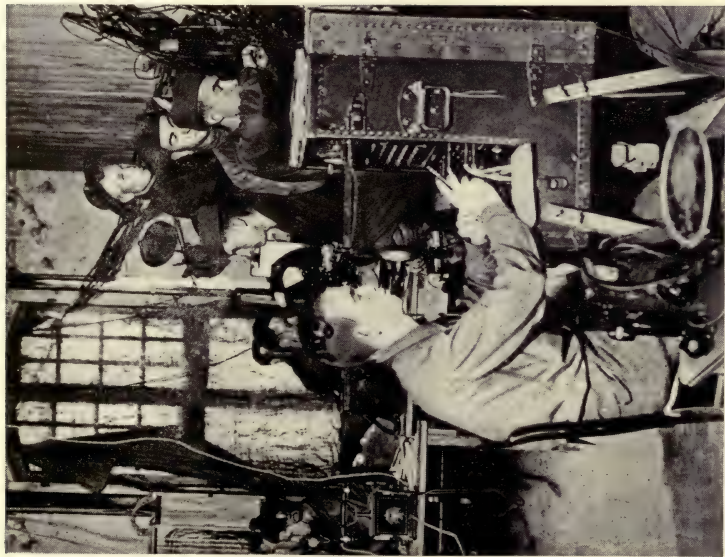


Figure 2. Portable army telephone exchange



Figure 3. Portable 4-line switchboard



Figure 4. Portable outpost switchboard



Figure 5. Signallers in gas masks talking with observer in a captive balloon

portable telephone outpost switchboard for outdoor installation under forest cover. As the telephone is carried nearer and nearer to the front line, it naturally enough assumes a less permanent appearance and becomes increasingly rough-and-ready. This is indicated by Figures 3 and 4. Of these, the former, Figure 3, shows a little four-line switchboard which has been set up, and is in use, on a street doorway. In all the apparatus, serviceability, adaptability, and simplicity were of prime importance, while finish and appearance were sacrificed.

As may be easily imagined, a very large amount of insulated twisted-pair telephone wire was needed to maintain telephone connection between all the elements of an advancing division. Very often there was no time or opportunity to pick up and reel in wire already in position, when new orders came to march. Consequently, arrangements had to be made to pay out new wire rapidly.

In the billeting and rest areas well behind the front, the telephone wires could be maintained without much trouble; but near the front trenches the wires were continually subject to damage by shell-fire. It was necessary to keep men constantly engaged on repairs, a very important, but very hazardous duty. Much of this work had to be done under long sustained gas-mask protection. A picture of two signallers in their gas masks exchanging telephone messages with an observer in a captive balloon overhead, through a pair of twisted wires in the balloon rope, appears in Fig. 5.

In the colloquial language of many telephonists, telephones and telephone circuits are apt to be "in trouble." There are "trouble men" appointed to each exchange. If a telephone man is said to be in trouble, the statement excites no remark; since that is part of the established order of telephonic things. When, however, the troubles besetting a telephone man are so numerous and inordinate as to do injustice to reason and probability, he is described as being "in grief," and then etiquette requires that sympathy should be extended. According to this philosophy of the art, the wires were "in grief" in

most front-line areas. It is recorded that, on one occasion, a telephone line 1 kilometer long, near Soissons, had 350 breaks in it, due to shell-fire. On another occasion, a Signal Corps officer had laid down eight separate and independently insulated telephone lines along the same shell-swept route to an artillery outpost, on the principle made famous by Shakespeare's Maria "If one break the other will hold" and so that one at least might be hoped to remain in serviceable condition for a few hours. To his dismay, a tank crossed this area shortly afterwards, caught the wires in its advance, and twisted them into a battered tangle of loose ends. In all such cases, reliance had to be placed on other methods of communication. These were wireless electric methods; but there were also flash-light signalling and flag signalling, where suitable protective cover could be secured. Moreover, carrier pigeons and despatch runners remained as ultimate resources.

Radio Communication in Front Areas. Radio communication was very extensively used in the war by all the armies. It is not entirely new in war; because it was used to a limited extent both in the Boer war and in the Russo-Japanese war. Nevertheless, it was a novelty of this war, in the sense that never before has such great reliance been placed upon wireless methods, and never have armies used it on so large a scale. Moreover, in the next war, which every one hopes may be long deferred, the expectation, from past experience and present knowledge, is that the radio apparatus will play almost as important a part in infantry tactics as the rifle.

The improvements in radio signalling as carried on in our army were of three kinds, which may best be considered separately; namely,

- (1). Improvements in the apparatus used for radio-telegraphy, particularly in vacuum tubes.
- (2). Improvements in radiotelephony, particularly as used for airplanes.
- (3). Improvements in radiogoniometry, or direction finding.

Vacuum Tubes. One of the most wonderful devices developed during the last few years, in connection with radio communication, is the vacuum tube. It is used as part of the sending apparatus for transmitting radio messages, and also as part of the receiving apparatus, as well as for various other accessory purposes. Fig. 8 shows two forms of such a tube. That on the right hand is structurally the stronger, and for army work has now superseded that on the left hand; but, in principle, they are identical. The vacuum chamber is a highly exhausted glass bulb, not much bigger than a hen's egg. At the center of this vacuum chamber is an incandescent filament in the form of a long inverted V, which receives heating current through two of the four insulated base pegs in the base. On each side of the filament, near to it, but not touching, is a vertical metallic wire grid or grating connected with a third insulated base peg. Outside the grid are two vertical metallic plates. These two parallel plates are electrically connected and make permanent contact with the fourth insulated base peg.

So long as the filament on the inside of the system is unheated, the filament, grid, and plate remain highly insulated from each other, although in close proximity within the vacuum chamber. No current will flow from one to another even under relatively powerful voltage. They are mechanically so near, and yet electrically so far. When, however, an electric current is passed through the filament, so as to heat it to cherry redness, the tube becomes a scene of marvellous activity, most of which remains invisible to the eye. The red hot filament disengages and throws out infinitesimally small particles, called corpuscles, of negatively electrified substance. If the plates are connected to the positive pole of a dry battery, these negative corpuscles, launched from the glowing filament, will be attracted to the plates, and will bombard them. In so doing, they will give up their negative charges to the plates, and cause a current to flow to the latter from the dry battery. The strength of this current can be greatly varied by varying the charge given to the intervening grid or metallic grating. If this grid is made positive,

the corpuscles being negative, will be accelerated, and pulled through from the filament to the outside plates at a rapid rate; whereas if the grid is made negative, the stream of bombarding corpuscles will be either retarded, or shut off altogether. Consequently, the application of a relatively feeble electric impulse to the grid can be made to control and deliver powerful electric currents to the plate. In this way, when the tube is used as a receiving device, it is made to amplify or enlarge the received electric current. It is then called an amplifier. On the other hand, when used as a generating device, it can cause a rapidly alternating and powerful current to flow in the generator circuit, under a very moderate initial stimulus. It is then called an oscillator. The capabilities of these tubes are astonishing. A series of them is frequently used as a multiple amplifier, in receiving and magnifying very faint radio signals. Each tube may successively multiply the strength of the received signal say ten times. A two-tube system can then amplify 100 times, and a three-tube system 1000 times. Amplifiers of as many as 20 tubes have been occasionally used, and 7-tube amplifiers are common; but the available ratio of amplification is not so high, when so long a succession is employed.

At first sight, it might well be considered that the vacuum tube was merely a laboratory device, and not a soldier's implement. It is fragile, delicate and easily injured. The conditions of military service in regard to transport are necessarily so severe, that any piece of military apparatus is commonly required to be capable of being dropped from the back of an army mule into a pool of mud and water, without suffering more than temporary embarrassment. Yet, by careful design, and the coöperation of experts in manufacture, the Signal Corps succeeded in producing vacuum tubes that would safely withstand the vicissitudes of hurried transportation followed by use in dugouts, trenches or airplanes. Large numbers of these tubes had to be manufactured, tested, sorted and shipped to the army in France, and many failures had to be encountered before success was attained; but the very great advances that

were made in radio-signalling during the war are attributable in large measure to that success.

As an example of what was accomplished by means of improvements in vacuum-tube receivers, it may suffice to describe a single receiving radio station among a number along the Allied lines in Europe. In an ordinary room of a brick building at one of the army headquarters, without any mast or external antenna, was a vertical wooden frame, about 2 meters square, wound with wire and rotatable about a vertical axis. Near the frame sat a soldier operator, with a pair of head telephones adjusted to his ears. These telephones were connected to the loops of wire on the frame, through a vacuum-tube amplifier of several stages. The room was kept fairly quiet, so that he could listen attentively to the faint intermittent buzzing note in the telephones. He sat writing messages in pencil on a pad before him for an hour or two, when he would be relieved by another soldier. Upon the wall, was a large map of Europe, on which were marked the principal radio stations of the Allied, neutral and enemy countries, with prominent electrical characteristics serving for their recognition. By turning the frame in the direction of the particular European radio station sought, its particular ether waves could be tuned to and detected in the telephone, almost to the complete exclusion of all others. Since these principal radio stations were in action at nearly all hours, each could be located in turn, and made to reveal the burden of its story as launched through the air in every direction over land and sea. In actual service, however, only one station would be followed continuously, and all that it said was written down on sheet after sheet of the message pad. These sheets were then carried, at regular intervals, to the Intelligence Section of the General Staff, for transcription and analysis. This eavesdropping on the ethereal whisperings around the world has become so common now in peace, as well as war, that it ceases to elicit comment; yet the recent great development is largely due to the Signal Corps of the armies and to the work of men in army uniform. In a certain sense, there has come to

be a new heaven and a new earth. Just as a spider on watch at the center of her net, becomes a combined spider and net organization, extended into space as a circular plane surface with physiological and nervous mechanism at the center; so a human being armed with a sufficiently powerful radio apparatus becomes in the same sense, a combined man and ether organization, pervading the whole world, and capable of initiating intelligent response over all the globe. This new man and ether organization is spherical and hollow within, since its present powers and realm terminate only a few meters below the globular surface of land or sea. Its outer surface, although roughly spherical also, is but ill defined as yet, albeit the realm of the creature probably extends everywhere as far above the globe as an airplane can soar. At the radiating and receiving center of this spherical being, with its tentacles all over the globe, is the physiological and nervous controlling mechanism, or the man power. Yet hundreds of men situated in different parts of the globe, and all pervading it, can radiate out their respective tentacles through the circumambient ether without conflict or interference.

In the earlier stages of the war, radio communication was employed not only to link up regimental, brigade, division and army corps headquarters, but also to link the infantry in the trenches with their regimental headquarters, and the observation airplanes with their artillery commands. The radio spark signalling was carried on from the trenches with the aid of a low portable air wire, strung in or close behind the trench, and worked from a shelter or dugout. It was open to the objection that the radio signals were capable of being read by friend and foe alike.

At a later stage of the war, the Signal Corps developed a portable and collapsible frame, one meter square, which could be operated on one of three different short wave lengths, by sustained oscillations from a generator vacuum tube. This set was found to be very reliable, and to be capable of sending or receiving signals not easily detected by the enemy. Two such

square frame sets are able to maintain communication between them, over a distance of 5 km. or more, even when each is operated in a deep dugout.

This war differed from preceding wars also in the fact that the artillery was fired at distant targets it very rarely saw, and was directed by targets, on which it did not aim. In such artillery practice, it becomes of vital importance for the artillery commander to know just where his own infantry forward lines are located, so as to keep his fire ahead of their advance. Portable radio loop sets are invaluable for this service, as they enable communication to be maintained at all times with the advancing lines.

Airplane Radio Communication During the War. In the early days of the war, the airplane became the eyes of the army. It was by reports from airplanes, that the British were able to make good their retreat from Mons to the Marne, during the fateful closing days of August, 1914. It was reports from airplanes that gave Foch the inspiration for his daring and epoch-making thrust through the German lines at the Marne on September 9th, 1914. It was airplanes that enabled a trench stalemate to be maintained for nearly three years thereafter, by eliminating the possibility of complete surprise on either side in large-scale strategy. Above all, it was airplanes that enabled long-range artillery fire to be controlled, the airplane observer signalling to the artillery outpost the effect of each shell round.

At first, the signalling between the airplane and the observer on the ground was entirely visual. The airplane showed a flag or released a visible signal. The ground observer replied to the airman by means of large flags, or other visible signals, displayed on the ground. These could only be read at a comparatively short range. Later in the war one-way radio communication was introduced into airplane fire control. The observer in the airplane let out a wire or trailing antenna and sent his reports in radio dots and dashes on this wire. A receiving operator in a radio station on the ground received these sig-

nals and delivered the message by telephone to the artillery officer. The reply was sent back from the ground to the airman by flags or ground signals; because although radio signals sent from the ground station might be received in the plane; yet the loud whirring of the airplane motor made such signals very difficult to detect in the telephone.

x At the entrance of America into the war, one of the first projects of our Chief Signal Officer, in connection with radio development, was to create a practicable airplane telephone set. Events happen so rapidly in the air, that airplane telegraphy with its dots and dashes may be all too slow at some critical period. The telephone becomes essential to successful communication. The difficulties in the way were very great, if only on account of the great noise in airplanes aloft. It has occasionally happened for example, that the pilot and the observer in one and the same airplane, have desired to communicate with each other, the distance between them being perhaps only a couple of meters. Shouting was of no use, and even an umbrella spanning the distance between the men would be unavailing for intersignalling purposes; so that they have actually given up the attempt to come to an understanding aloft, and have wended their way down to the earth, in order to stop the engine and talk together. The problem of telephoning aloft from one airplane to another or to a radio station on the ground was thus most ambitious and difficult.

The problem was successfully solved, however, with the aid of the experts of the large telephone companies. A vacuum-tube transmitter and a two-stage vacuum tube receiver were developed, which could readily be carried on an airplane. A carefully designed helmet, with rubber caps enclosing a telephone tightly over each ear, eliminated most of the engine noise, and then a trailing antenna from each airplane enabled signals to be exchanged. A reel, like a large fishing-rod reel, mounted on the outside of an airplane fuselage pays out and reels in the antenna wire with a metallic weight on the end, which from its shape is called a "fish."



Figure 6
Brigadier-General Edgar G. Russel
The Chief Signal Officer of the A. E. F.



Figure 7
Major-General Squier
Chief Signal Officer, U. S. Army

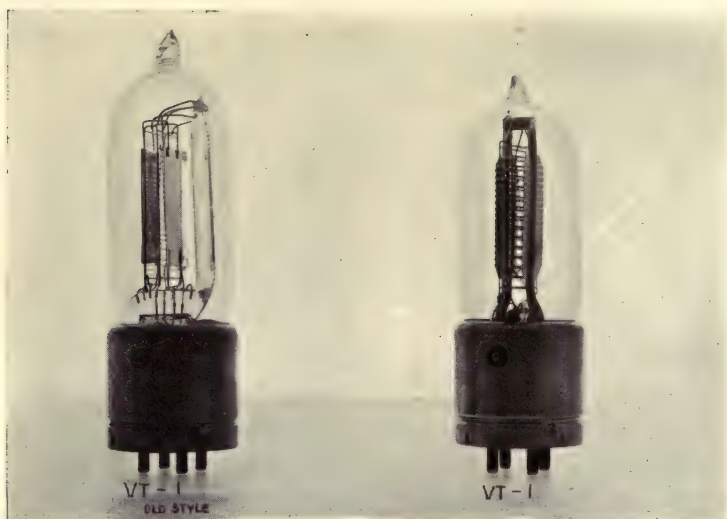


Figure 8. Types of vacuum tube



Figure 9. Airplane radiogenerator

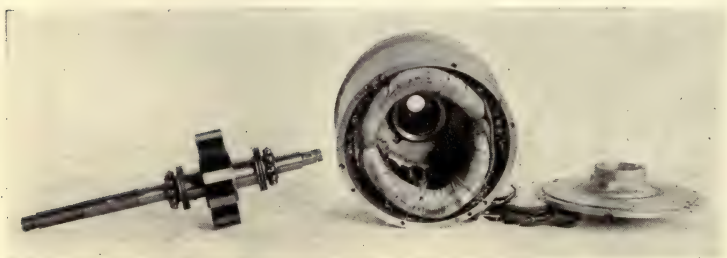


Figure 10. Interior parts of radiogenerator

In order to supply electricity for the airplane set, a special little dynamo machine, of the windmill type, is supported underneath the fuselage, so as to be driven by the motion of the plane through the air. A picture of this machine with its two windmill blades appears in Fig. 9. The apparatus is tapered away towards the rear in stream-line fashion, so as to offer as little useless opposition to the air as possible. The interior parts of one of these airplane radiogenerators are presented to view in Fig. 10. These little windmills are required to rotate at a nearly constant speed over a wide range of airplane velocity. A well-designed fan naturally keeps its speeds of rotation nearly in direct proportion to the speed at which it is pulled through the air. In this case, however, it ought not to change speed when the airplane goes faster or slower. This means that the fan has to be designed very badly, judged from the ordinary standpoint. One officer very proudly declared that he had devised for this purpose the worst fan design in heaven or earth, in order to meet the required conditions. There is, moreover, a vacuum-tube automatic compensator in the ogival apex of the dynamo case, which also aids in maintaining constant voltage over a wide range in speed through the air.

The airplane telephone set is also ordinarily so arranged that the observer not only can telephone to his ground station up to a distance of say 20 kilometers by radio, but also with the pilot of the plane, sitting close to him in the next cockpit, by ordinary wire methods.

Before the Signal Corps developed this aerial telephone system, each airplane necessarily became an individual fighting unit with only limited opportunities for concerted action after it left the ground. A squadron of airplanes might fly together under the leadership of its squadron commander, and follow a preconcerted procedure. If, however, any unforeseen event occurred during the flight to upset the original plan, the commander had very little hope of communicating a change of orders to his subordinates. The airplane telephone completely altered

this condition of affairs. The squadron commander could keep in communication with all his planes, so long as they did not get out of the telephonic range from him of say 5 kilometers. A voice-commanded squadron then becomes a new fighting unit of greatly improved power of manœuvering. In practice, it is customary to give a complete sending and receiving radio set to the squadron commander; but to give only a receiving radio set to each subordinate plane. The subordinate officers can then receive orders, but have no means of answering back. When an order to the squadron is given by radio, during flight, the planes acknowledge it, each in turn, by a quick dip to apprise the commander of their acceptance. If, however, a plane fails to get the order, it gives a "wriggle" laterally, which indicates to the commander that the order should be repeated.

Another great advantage of a voice-controlled airplane squadron is that if a warning comes of a threatened attack from a distant but rapidly approaching hostile squadron, the airmen on duty at the hangar can instantly board their planes, get off into the air, let out their air wires and commence climbing to the altitude of expected attack, without waiting for detailed instructions, which can reach them later by radio as the situation develops. In this way, precious moments needed for climbing can be utilized without loss of manœuvering power or adequate information for defense. Many a hostile airplane has thus been intercepted and overthrown, that could otherwise have probably dropped its bombs on an undefended target.

Improvements in Radio Goniometry, or Direction Finding, during the War. The invisible electromagnetic waves of radio-communication radiate out in straight lines from the transmitting station over every direction of the compass, like the rays of light from a lamp or an open fire. Indeed, these electromagnetic waves are agreed to be identical with light waves except in regard to their length. Whereas the waves of light that are visible to the eye are only a fraction of one *micron*, or one millionth of a meter, in length, the waves of light which

carry on radio communication and are entirely invisible to the eye are from, say 20 meters to 20 kilometers in length. A very valuable property of such long waves is that they bend around, and conform to, the spherical surface of land and sea; whereas short and visible waves, except in extreme cases, maintain straight lines in their advance. If, however, the eye responded to radio waves, we might expect to perceive the compass bearing and direction of their source, however remote it might be. Since the human eye is unresponsive, an artificial eye has to be resorted to, which shall enable by its indications the electrical bearing and direction of the source of any radio waves that may be received. Such an instrument is a radio-goniometer, or radio direction finder.

A goniometer may be mounted on the roof of a small radio house or on the roof of a traveling radio car, or fixed on an airplane. The goniometer in any case consists of a square wooden frame of insulated wire pivoted on a vertical axis, and rotatable by an observer underneath and inside the house. The observer connects the ends of this rotatable coil to a tuning condenser and a sensitive vacuum-tube amplifier. He then listens for signals in his head telephone.

When the plane of the frame coil is parallel to the radio wave front, the radio waves passing the frame produce no electric disturbance in the observer's circuit, and no sound in his ear. On the other hand, when the frame coil is set perpendicular to the arriving radio waves, the electric disturbance and telephonically received sound will be a maximum. One way of getting the bearing of the radio station, which is sending the signals, is to rotate the frame until the sounds in the telephone pass through zero. The frame is then perpendicular to the direction of the station sought, and the observer can read off the direction from a horizontal disk at the foot of the frame spindle. By practice, an observer can locate, in this way, the electric bearing or direction of a radio station, within a certain small angle of uncertainty. In the case of a powerful station, only a few kilometers away, he can perhaps assign the direction

to a single degree of arc. If the station is feeble, and far away, he may not be able to tell the exact direction to perhaps 20 degrees. His observations do not tell him the distance of the station whose direction he assigns, except as he may guess the distance from the strength of the received signals. But if there are two, or still better, three such houses equipped with radio goniometers, and their positions are properly marked on the map; then if they take simultaneous cross bearings of the same sending radio station, the signals from which are tuned to by all, these cross bearings will locate that sending station definitely on the map.

The Allied armies in Europe maintained a coördinated series of goniostations at some kilometers distance behind the fighting line and at intervals of about 15 kilometers along it. Radio watch was kept in these stations, day and night, by skilled observers, who thus patrolled the ether. Some of them directed special attention to giving notice of the approach and direction of hostile airplanes having radio equipment. Others listened for radio messages from one hostile ground station to another on the enemy's side of the line, striving to record both the message and the direction of the station whence it came. Again, others listened for and responded to orders from Allied radio officers in charge. Each goniostation took up its assigned duties in this coördinated patrol work. A regular code of radio procedure was planned and executed, whereby all observers regularly watched and recorded; but emitted radio signals only on order. The ordinary reports from each goniostation were transmitted by wire, at regular intervals, to the intelligence department of the general staff, and emergency reports upon the instant. By dovetailing simultaneous directions and bearings from adjacent goniostations, headquarters was able to plot the positions of enemy radio stations at various distances behind the opposing lines, to decipher the enemy's code messages, and to keep statistics of his radio traffic. The imminence of a threatened attack from the enemy could be predicted often days in advance, by studying this collected material. These col-

lected radio data and deductions were communicated, at suitable intervals, to the general staff and neighboring corps.

The enemy was evidently well aware of these radio hunts upon his preserves, and took pains to evade detection. Thus, he changed the code names of his radio stations at very frequent intervals. He limited the number and length of his messages as much as possible, and used short wave lengths. The shorter the message, and the more unusual the wave length it employed, the harder it was for our radio scouts to catch the message, and fix its direction of origin. On the other hand, constant practice trained the observers so that they could detect a new wave length, tune to it, take in and record the code message, and get its radio direction, all in a few seconds of time. The patrol became a strife of experts on each side with invisible weapons in the ether. Some observers seemed to develop a peculiar ethereal sense, or aptitude for hunting and capturing radio raids. Each goniostation so manned sent out invisible and ethereal feelers into space over a range of a hundred kilometers or more, because all this fishing was at relatively short radio distance.

The goniostations that watched for radio signals from enemy airplanes could sometimes supply captured code messages to headquarters, which, when deciphered, would enable the artillery officer there to warn by wire some particular battery on which fire was impending from hostile batteries, to take shelter in time. Moreover, when the radio officer in charge of a "radio net" received sudden warning of an approaching hostile radio-equipped airship squadron, he would notify his fighting planes at the nearest hangar to take the air and order certain of his goniostations to take swift radio bearings of the oncoming raiders. The instant these bearings were reported, they were laid out on a special map with a very swift geometrical apparatus, and the distance as well as the direction of the hostile plane from hangar read and given to the fighting pilots, who took their direction upwards accordingly. In this way, many raids were intercepted by fighting planes and not a few crushed.

The success of such manœuvres depended, perhaps, upon skilful goniometry. A few seconds of time meant victory or defeat.

Improvements in Aerogoniometry, or Direction Finding from Airships. Just as ground goniostations were able, in the manner above outlined, to measure the direction of a distant and invisible airship which was emitting radio signals from its trailing antenna; so conversely, it became, to a certain extent, established practice among the Allied air services, during the war, to find the direction of certain beacon radio stations from on board a flying airship, and so, by cross bearings, locate the observer's position over the land or sea. In particular, there were three widely separated beacon radio stations in Great Britain, which, for two minutes just before each hour, successively emitted signals corresponding to certain distinctive letters of the alphabet, on a definite wave length. A flying observer, in cloudy weather, wishing to locate himself at such times, could find the radio bearing of each of these three beacon stations, and so lay down his position on his map to a certain degree of precision. The radio bearing of a beacon station could be measured on a steady airplane course to about one degree of arc. The precision of the fix obtained from cross bearings would, in each case, depend upon the distance of the flying plane from the beacons; but ordinarily a fix within 10 kilometers of the actual position was considered satisfactory. A distance of 10 kilometers would be passed over in about three or four minutes of rapid flight. These gonio bearings were obtained from coils mounted on the airplane, and commonly within the fuselage, so arranged as to be rotatable by the observer from his seat. Large airplanes, of the long-distance bombing type, often carried a navigating officer, who, among his other duties, took gonio measurements during flight, when the darkness or cloudiness prevented him from recognizing his position over the ground. It is clear that this method of determining positions during flight by aerogoniometry, largely developed under the pressure of the world fight, will play a

definite part in the future development of flying, in peace as well as in war.

Improvements in Ground Telegraphy. In addition to radio communication without wires, the Signal Corps employed in our army, and in common with our Allies, another system of so-called wireless electric communication, which consists in laying a short length — say 75 meters — of insulated wire on the surface of the ground in a straight line parallel to the front trenches, grounding each end of this wire, usually by steel spikes driven into the soil, and inserting in this wire, say at the middle of its length, a relatively powerful electric buzzer sending apparatus, worked from a portable storage battery. Any similar length of wire parallel to this, and not more than say 2 or 3 kilometers distant therefrom, with its ends also grounded, and with a delicate telephone receiver inserted in it, enables the buzzer signals from the distant sending wire to be picked up and read by the listening operator, who may, perhaps, be located in a dugout on the front line. This communication between two short parallel grounded wires depends upon ground conduction, magnetic induction, and radio action, all combined in certain proportions, that vary from case to case. The French who, as a nation, are always logical in thought, and precise in language, have called this *télégraphie par sol*, abbreviated T. P. S., or as it has been repeated in our army, "ground telegraphy."

Ground telegraphy apparatus has its advantages in being portable and well adapted to rapid infantry advance over a short range. It can be put down and picked up again, as rapidly as the men can drive short steel spikes and pull them up again. The short length of wire is likely to escape destruction from exploding shells, for a little while, during an advance. Disadvantages are, on the other hand, that the coded messages can be read as easily by foe as friend. As soon as T. P. S. messages are picked up, the terrain from which they may emanate at once invites the attention of opposing artillery. The Germans, who also employed a T. P. S. system, resorted

to various methods to hamper our use of it, such as sending powerful dynamo currents through the ground in the neighborhood, in order to deafen the listener and make the signals unreadable.

Experience with the system, while greatly developing it in the war, seems to have indicated that the short-wave radio-loop system is much more effective and advantageous; so that it is doubtful whether the T. P. S. system will play much part in another war; whereas the use of the radio system is likely to be greatly increased.

Tree Antennæ. It was discovered by the Chief Signal Officer in 1904, that almost any living tree, of suitable height, could be made use of as a receiving antenna for radio communication, if a nail were driven into the tree trunk at a short elevation above the ground, and radio apparatus connected by a wire to this nail and to ground. In other words, a growing tree could be made to serve for radio reception, in place of a tower, or high pole and wire. Every tree is thus, in a certain sense, a makeshift substitute for a radio antenna. An intensive investigation of this remarkable phenomenon, made during the war by the Signal Corps, showed that, with modern amplifiers, signals could easily be read in America from powerful European stations, like Nauen in Germany, using a tree and short wire instead of a mast and high wire. Moreover, such a tree antenna enabled goniometric measurements to be made of the direction of the incoming signals, with the aid of relatively small rotatable frame coils.

The investigation has shown that a radio observer who desires to receive long distance signals, as distinguished from transmitting them, need only locate a suitably high tree, and connect his amplifying apparatus to it by a wire preferably reaching up to about two-thirds of the total height of the tree. If anyone should ask to-day what are the secrets which the trees seem to whisper to one another in the woods, a scientific, as well as a poetic, answer, might be that, in a certain sense,

they faintly whisper the secrets of all the radio communications of the world.

Increase of Radio Precision and Range. It has been estimated that at least in two directions, the war advanced applied science more in four years than perhaps might have been accomplished in twenty or thirty years of peace; namely (1) in airships or airshipping, and (2) in radio communication. The great number of radio messages, passing simultaneously through the air, forced the necessity of learning to tune sharply, in order to effect precise and accurate inter-communication in the Allied armies. Moreover, the ranges of radio signalling by telephone and by telegraph were greatly increased. In regard to radio-telegraphy, the range was increased until it actually encircles the globe. It was found during the war that radio signals emitted at Carnarvon, in Wales, were detected and read successfully at Sydney, New South Wales, Australia. Any terrestrial globe will show that the British Isles and New South Wales are nearly diametrically opposite. We may, therefore, expect that, in the future, radio telegraphy will expand not merely across oceans, but around the world in all directions simultaneously.

The time that it takes an electromagnetic wave to run around the globe, from the radio station of emission to an antipodean radio station of reception, has not yet been actually measured; although the time of transmission of radio signals has been determined photographically, between Washington, D. C., and Paris, France, an overseas distance of 6175 kilometers, as 0.021 second. The wave travels very nearly as fast as light *in vacuo*; i.e., 300,000 kilometers per second. Since the distance from pole to pole is 20,000 kilometers, the time for any wave to travel to an antipodean station should not much exceed one-fifteenth of a second. Consequently, all parts of our world have shrunk, during the war, to something less than one-tenth of a second of utmost separation or remoteness. How hopeless, in the future, must such a world be without a league, nay

a perpetual Congress, of nations, a single system of weights and measures, a single trunk language, and a paramount international law! Disunity on this planet has been doomed by radio. Law and order will necessarily have to be maintained, not merely here and there, but everywhere on a tenth-second world. If the great war has brought death to, say, twenty millions of persons, and horror and hate to many more, yet it has brought the reality of ethereal contact, and the potential future blessings of almost instantaneous intercommunication, through radio signalling, to all the children of men.

XIV

CONTRIBUTIONS OF METALLURGY TO VICTORY.

HENRY M. HOWE

IN this story of the contributions of metallurgy to victory let me first tell of that which was of transcendent importance, the human element, and then consider some of the technical advances, of the new alloys, and of the new adaptations of old ones. In the space available only a few striking and typical cases can be given. To tell all that was noble or noteworthy would need a shelf rather than a chapter. I have naturally written of those events most familiar and readily verified.

The metallurgist's great contributions were the wonderful increase in the production of ordnance material, and the equally wonderful spirit of coöperation which underlay it. It is not simply that each steel-maker who knew how to make steel fit for cannons turned his manufacture from peace to war products, and increased the scale of his operations, but that the few, the perilously few, who had this knowledge from long and costly experiments, from risking their solvency, and from every kind of strenuous endeavor, deliberately gave it freely to their own competitors, actual and potential. Only thus was it possible to create the mechanism which could make the enormous quantities imperatively needed. Each owner of furnaces whose lack of special knowledge had till now restricted his work to the cruder kinds of steel must now be taught how to make the best. Where this giving was due to patriotism it was to high patriotism; where it was to enlightened self-interest, how clear was that enlightenment! The ordnance officers who urged this course had indeed the strong argument, "What good will

the exclusiveness of your knowledge do you if Germany wins and takes everything, down to the clothes on your back, exclusiveness included? Better to tell your competitors your secrets than to run the risk of beggary and blows for yourselves and dishonor for your women."

The case of France is the most striking. Her northeastern iron district, her most important, was overwhelmed by the first German onrush, and she thus lost about 81 per cent. of her pig-iron capacity and 63 per cent. of her steel-making capacity. But in about two and one-half years she nearly tripled the number of her blast furnaces, and increased that of her open hearth furnaces by about 60 per cent. During the war she increased her annual production of rifles 290 fold, of machine guns 70 fold, of 150 mm. shells 225 fold, and of 75 mm. shells 15 fold, the production of these last reaching the enormous number of 200,000 a day. Far as these numbers are beyond our mental grasp, they suffice to correct the impression that it is by necessity that France has usually devoted herself to the exquisite perfection of her products rather than to their quantity. Her gigantic output of munitions, for her own army, for ours, and for those of five other Allied nations shows that, in habitually devoting herself most strikingly to products beyond the skill of all other people, she is following choice and not necessity.

The part played by an illustrious French ironmaster, Dr. Schneider, may well be recorded. He controls about 250,000 workmen at Le Creusot and his many other steel works, ship-yards, iron and coal mines, optical works, machine tool works, electrical works, Diesel engine works, locomotive works, bridge and other works. He supplied about three-quarters of all the artillery used in the war by the French, including the Schneider 21-inch guns. He provided the American Army with about half of its heavy artillery, and all of its field artillery, besides sending much to the Belgian, Italian, Roumanian, Russian and Serbian Armies, and making enormous quantities of the most varied war products, tanks, aircraft and machine guns. This

achievement is not dimmed by our sending ordnance of other kinds to Europe on a like scale, As early as March, 1915, foreseeing our eventual entry into the war, he sent engineers to introduce into this as well as other countries the French methods of making shells and gun steel, thus lightening the work of the French commissions later sent to buy munitions.

Like Dr. Schneider's story is that of the Perrone Brothers, President and Chairman of the Ansaldo Company of Genoa, makers of ships, turbines, locomotives, electrical machinery, and like products.

Seeing clearly, and long before the war, the menace to Italy in the German peaceful penetration all about them, they pledged themselves beside their father's coffin to keep all German interests and influence away from their great industry. When we remember how the treacherous Teuton succeeded in controlling Greece and in causing Russia's perfidy towards Roumania, we are hardly surprised that this strictly Italian company, with its wonderful possibilities, could get no orders from its own government. Nothing daunted, the management started at the beginning of the war to turn its plants into gun-making establishments, and actually completed two thousand cannons before it could get an order. Then, when the terrible Caporetto disaster came, the government turned to it for guns, and seems to have been greatly surprised to learn that these two thousand guns were even then on hand ready for immediate shipment. Thereafter, indeed, came orders in plenty, till the company, now employing a hundred thousand men, had made ten thousand guns.

To the stupendous task of making these was added that of financing the manufacture, for, plenty as the orders now were, there was no pay. At one time the government owed the Ansaldo Company about one hundred and forty million dollars. In order to carry so great a load a combination of banks had to be made.

In the last two years of the war this company bought and brought from America in its own steamers nearly fifty million

dollars worth of war material. Besides 10,000 cannon it made 3000 airplanes, fifty million projectiles, and great numbers of warships, torpedo boats, and submarines.

To illustrate the British metallurgical contributions my story may well give some examples of the work of one of the very most interesting figures in modern metallurgy, Sir Robert Hadfield, inventor, general of investigators, vitalizer of societies, astonishing captain-major of industry, and inexhaustible fountain of enthusiasm to all about him.

Of his manganese steel helmets I tell in a later section. Other important war uses of this material were found, of which I may not tell.

In the terrible autumn of 1914 he was asked by the War Office to install several factories specially planned for making the high-explosive shells of which the Allied armies were in such grave need. It was characteristic of his exuberant driving power that he built two plants and had them delivering finished shells in one case in 5 months and 3 days and in the other case in less than six months after beginning to build. He also built new plants and converted existing plants, giving them a weekly capacity of over 8,000 of the important 9.2 in. Howitzer shells. Before the war a weekly production of 200 such shells was about the normal.

The flexibility with which he adapted his works to new and very difficult products is illustrated by his making 3000 gun tubes of calibers running up to 9.2 inches, and 3400 trench howitzers, though he had never made either guns or howitzers before March, 1917.

It was by such feats that the steel makers of Great Britain and France enabled their battered armies to hold back the German flood till the general ammunition campaign became effective later on.

Sir Robert's firm made nearly $2\frac{1}{2}$ million shells of about 20 different kinds for the British Army, and 1 million of 37 different kinds for their navy, including the immense armor piercing shells, weighing a ton and a half each, for the 18-inch monitor

guns. The gun itself weighs about 150 tons, and can send its shell more than 30 miles. The total Hadfield production of shells was equivalent to nearly 30 million 18-pounders, and their total production of all kinds of steel was about 750,000 tons, valued at about \$160,000,000.

American Contributions. When we entered the war it was wisely decided that our ordnance makers should concentrate their attention first on making the products with which the Allied armies as a whole were least well supplied; and second and chiefly on laying the foundations for an overwhelming production of ordnance for 1919 and 1920, even though this meant deliberately restricting the joint production of the Allies for 1918 to but little beyond their bare necessities.

The former of these principles is illustrated by our throwing the chief accent on the manufacture of explosives, propellants, and certain specific kinds of shells, because the British and French works already had capacity sufficient for supplying all the Allied armies, including our own, with most kinds of guns throughout 1918, and with most kinds of shells at least till June of that year.

If, as seems probable, the German general staff was allowed to learn of the second of these two principles, our straining everything to create establishments which could prepare the vast quantities needed for an irresistible onslaught in 1919, it would naturally do as it did, stake all on a series of titanic efforts to break through the Allied line at all costs before our help could come, and when these failed abandon hope. If Château-Thierry could happen in our unreadiness, what would we be when ready? Why fight and bleed till then?

In order to weigh fairly what we did in gun making you must understand our shameful situation in having before the war only two establishments at which great guns of first rate quality could be made. Think of that, the richest country in the world in natural resources, in assets in general, and in power of industrial organization, with a hundred million inhabitants generous to prodigality, and only two establishments, public or

private, which had the knowledge and the tools needed for making first-class cannons. No administration in the last twenty-five years can escape part of the blame for failing to make our people understand how grossly we were unprepared.

Happily we can turn from this humiliating ante-bellum state to a war record of which our children and grandchildren may be proud.

The contrast between the two private ordnance works and six government arsenals before the war, and the nearly 8000 establishments working on ordnance contracts on Armistice Day, is striking enough whatever allowance we make for the great number of ordnance items apart from guns at the end of the war, when there were more than 100,000 distinct items in the American ordnance catalogue.

The story of the "Gun and Howitzer Club" is an interesting example of the way in which we worked. In addition to our two skilled cannon-makers there were plenty of steel makers who could readily be given this great skill by filling in the gaps in their already great knowledge. They were the material out of which we must needs make gun makers. To this end the Gun and Howitzer Club was formed. It was called by its Chairman the "Greenhorns' Club" with the wise purpose of impressing on the experienced steel makers and ordnance officers who were its members their ignorance of many essentials of gun-making procedure. They could already make very good steel, yet not steel good enough for guns. Moreover, in their long and very intelligent practice many of them had developed expedients which would be of help in hastening and cheapening even the practice of the best gun-steel makers.

The purpose of the club was thus to pool the knowledge of the actual and potential gun makers, which meant to replace their firmly established policy of secrecy with its opposite. In order that so complete a reversal of trade policy should even be considered, it must be proposed by men whom the trade held not only in perfect confidence for their uprightness and good sense, but also in affection. Such were the men who led

the difficult but absolutely necessary work of this club,— Mr. A. A. Stevenson, its Chairman, and Colonel William P. Barba of the Ordnance Department, himself a most accomplished maker of guns and gun steel.

So wisely and so energetically was this pooling pressed that by August, 1918, twenty-one of the most capable makers of gun steel and of gun forgings, indeed all of those supplying either the army or the navy, were brought into the closest relations, so that at the frequent meetings of the club at the various gun works its members interchanged even the most secret information without reserve.

The value of this organization, loose as it was, may be inferred in a rough way from a comparison of our trifling production of 55 finished guns per annum before 1917, with our production in October, 1918, at the rate of 24,000¹ sets of forgings for guns between 3-inches and 9.5-inches in diameter, though three of the gun factories had not yet completed their machine-tool equipment.

This substitution of coöperation for segregation was of such great and clear benefit to all that the Greenhorns' Club is still working with the Ordnance Departments of both army and navy, to design their new equipment in such a way that its production may be quickly expanded to enormous dimensions when the next demand comes.

Two cases of very rapid construction of gun factories deserve mention. The Tacony gun plant, which cost \$3,000,000, was built in 7 months, between October 11th, 1917, and May 15th, 1918, in spite of the extraordinarily severe winter. On June 29th, 1918, its first carload of gun forgings was accepted and shipped, eight and one-half months after breaking ground.

The new works of American Brake Shoe and Foundry Company began shipping howitzers seven months after breaking ground.

At the end of the war we were making gun bodies ready for

¹ America's Munitions, 1917-1918, Benedict Crowell, pp. 43-44.

mounting at the rate of 832 per month, while England was making them at the rate of 802 and France at the rate of 1138 per month; and we were making machine guns and automatic rifles nearly thrice as fast as England and more than twice as fast as France.

How rapidly we increased our production of ammunition is shown by the fact that about one-quarter of all the high-explosive 75-mm. shells, and nearly 40 per cent. of all the adapters and boosters for them which we machined up to November 1st, 1918, passed inspection in October, 1918.

By the end of the war we had at least 42,000 workmen engaged in the manufacture of great guns, including their carriages and fire-control apparatus. Though, because of our initial lack of preparation, our Army Ordnance Department sold to our allies much less than half the ordnance that it bought from them, yet our country sold them five dollars' worth of ordnance and materials for conversion into ordnance and munitions for every dollar's worth we bought from them. We may well consider how far the resulting adverse trade balance of our allies represents a normal debt, and how far a pound of flesh from next the heart. Before our belated entry into the war we knew that they needed these arms to defend us as well as themselves from annihilation. If I arm a watchman to defend both himself and me, which is the debtor? Should he alone pay for the arms which he uses in our common defense, while I remain at home in supposed safety?

Simplification of Cannon Making. The manufacture of cannons was materially hastened and their quality improved at the same time by decreasing greatly the amount of forging which they undergo. This seems at first a most uninteresting and purely administrative measure, but on examination it turns out to be due to basic physical considerations of very great interest, which might well escape attention. We ask at once "Why are cannons forged at all? Why do we follow the tedious and expensive plan of casting the molten steel in a very large ingot, as the crude mass into which the steel is first

cast is called, with a cross section about four times that of the cannon itself, and then forge it down with extremely costly presses and with a very great outlay of energy, into its final shape? Why do we not proceed as in making a statue, and cast the molten metal directly into a cannon of the exact size and shape in which it will be used? In short, why are cannons forgings instead of being simply castings?"

Partly from copying blindly the procedure which was necessary when cannons were not cast from the molten as a single piece of steel, but were built up from a large number of lumps of wrought iron, which had to undergo a great amount of forging in order to weld them together. Apart from this minor and valid reason is that the kneading under the hydraulic press closes up any small cavities which form in the solidification of the molten mass. But the chief motive is that this kneading may lessen the extreme heterogeneousness which such a cast mass necessarily has, as I will now show.

Solidification is an extremely complex process of differentiation. This differentiation is familiar, though not by so long a name, to every country bred boy, who knows that if a vesselful of cider is frozen half way through, the half which remains unfrozen, surrounded by the frozen part as by a jacket of ice, is far more stimulating and joyous than the original fermented juice of Eve's fruit. There is no more alcohol present in the mass taken as a whole than when we started, but that which is present has been concentrated in the unfrozen "mother liquor," because of this differentiation in freezing. The earliest frozen layers in the act of freezing reject part of their alcohol content and thus concentrate it in the mother liquor.

A parallel process occurs in the solidification of a steel ingot. The carbon as well as the harmful impurities, phosphorus and sulphur, which we have failed to remove completely in the purification of the steel, become concentrated progressively during solidification in the remaining molten metal. Each successive layer of solid steel, deposited from

the still molten interior upon the already solid white-hot jacket of steel which encases it, becomes thus richer in carbon, phosphorus, and sulphur than the preceding layer, so that the content of these elements increases progressively from the skin to the axis of the completely solidified ingot.

But this is not the worst of it. The steel solidifies not in successive layers like the leaves of a gigantic onion, but rather in great columnar or pine-tree crystals protruding out at any given moment into the still molten interior. As solidification proceeds these trees grow not only at their tips but also at the ends of their tree-like branches, which thus in time interlace, and thus landlock part of the enriched mother liquor. The result is that, when solidification is complete, the ingot as a whole has a dendritic structure, with these elements concentrated in part between the trunks and branches of the pine trees, and in part concentrated progressively towards the axis of the ingot, or more strictly towards the last freezing part. This structure may be likened to the veining of marble. In each case the mass is substantially free from cavities, and even from porosity, but it is coarsely heterogeneous.

The carbon and phosphorus which are thus concentrated embrittle the metal locally, giving rise to brittle regions scattered through the mass, somewhat like brittle links in an otherwise ductile chain, lessening the resistance of the whole to shock.

The main purpose of forging is to lessen this heterogeneity by a species of kneading which mixes up the various parts, and in particular lessens the distances which diffusion has to cover in order to give uniformity. Kneading thus being a good thing, give us plenty of it. It was most readily given by reducing the cross section of the ingot under the hydraulic press, and simultaneously lengthening it. But in order that this cross section should thus be reduced greatly it must initially be much greater than that of the finished piece, formerly four times as great. In trade language, there was a reduction of four to one. Even before the war many of us insisted

that this was exaggerating the disease in order to use more medicine for its cure; that to give the ingot this great cross section was to retard the solidification greatly, and thus to increase the differentiation which it is the purpose of forging to palliate. We insisted that a reduction of four to one was excessive.

Fortunately the needs of the war gained us a hearing. We needed cannons, and as quickly as possible. Clearly a reduction of two to one takes only half as long as a reduction of four to one. This consideration, backed up by the assurances of the most intelligent experts that the faster solidification of the smaller ingots would result in a better product, at last led to casting the steel in much smaller ingots, calling for a reduction of only two to one instead of four to one. This is typical of a whole class of cases in which the necessities of war induced the authorities to depart from bad practices which had rested on superstition or ignorance.

Hadfield's Manganese Steel for Helmets. In using Hadfield's manganese steel, an alloy of iron with about 12 per cent. of manganese and 1.25 per cent. of carbon, for the helmets of the American and British Armies, the idiosyncrasies of a very remarkable material were utilized in a striking way. Even in our early attempts to use it, we saw some decades ago that, in addition to its extraordinary combination of hardness with ductility, it had some obscure peculiarity which prevented our foretelling with confidence whether it would fit any new service proposed. Shortly before the war we found that this peculiarity consisted, at least in part, in its increasing greatly in hardness on even slight plastic deformation, that is on being bent, twisted, compressed, lengthened, or otherwise forced beyond its elastic limit, so that it takes permanent set. This plastic deformation seems to precipitate an overdue allotropic change of the iron itself, from the gamma or non-magnetic ductile state to the beta or hard brittle state, given to common steel by rapid cooling from above a red heat. Thus a rail of manganese steel when first laid in the track consists

throughout of the ductile and rather soft gamma iron. The pressure of the passing wheels soon strains a very thin layer on the top of the rail beyond its elastic limit, and thus shifts it to the hard beta state, which because of its hardness resists the abrasion of the wheels, while its integral union with the ductile gamma body of the rail prevents it from breaking readily.

A helmet is pressed into shape from a flat sheet. In thus pressing a helmet of manganese steel the incidental plastic deformation transfers enough iron from the gamma to the hard beta state to make the mass hard and rigid, while leaving enough ductile gamma iron to prevent shattering under the impact of the bullet, and the wounding of the wearer by flying fragments. Hence this alloy, in spite of its low ballistic resistance when in the form of heavy ship's armor, has great ballistic resistance when pressed into helmets. Many millions of these manganese steel helmets were worn by the soldiers of the American and British Armies. Indeed the manganese steel made for this purpose by the Hadfield firm alone represented nearly four million helmets. They are incomparably more resistant than the French helmets, which strangely enough were made of a soft weak steel. The German helmet was about 12 per cent. thicker and about half heavier than the manganese steel ones, weighing 37 ounces against the former's 25½. On the other hand it protects the back of the head and neck much better.

A helmet must neither perforate, splinter, nor indent deeply. Its wearer may be killed by the helmet's indenting so deeply as to fracture his skull sand-bagwise, even though it is not actually perforated by the bullet.

Inestimable as was the service rendered by this helmet, a fair weighing of its merits and defects against those of the German helmet, and of the material and design developed in the experiments carried out by the American Army Ordnance Department jointly with the Engineering Division of the National Research Council, remains to be made.

The Use of Cast Iron for Bursting Shells. With the steel works representing more than 60 per cent. of the French steel production overwhelmed by the first German onrush, the French wisely adopted cast iron as one of the materials for their bursting shells, thus releasing their small remaining steel production for high-explosive shells, cannon, and other imperatively needed ordnance. Fortunately, the manufacture of these cast iron bursting shells had been developed at the Douai arsenal before the war.

Among the many advantages of this step were that the making of these cast iron shells could be begun immediately at most of the numberless iron foundries scattered all over the country; that additional foundries for making them could be built far faster than steel works could; that the processes of production are much simpler than the steel making processes chiefly because cast iron is very much more fusible than steel; that the cast iron shells can be made from relatively impure and very abundant raw materials, thus leaving the scanty supply of the best materials for steel-making; that they are far cheaper than steel shells; and that their manufacture calls for far less fuel.

Ordnance engineers have been reluctant to use so brittle a material for shells, lest they break in the gun and thus cause it to burst. Even a thread left in the barrel of a revolver in cleaning it will lead to its bursting when next fired. But with the Germans at the Marne it was imperative to increase the shell production by all possible means, even if this led to the occasional bursting of a gun. Better one gun crew in a hundred blown to shreds than Paris taken.

The risk of gun-bursting is probably less than it seems at first, in view of the general use of cast iron in this country for carwheels, even those of passenger coaches on express trains, and of the insignificant number of the accidents caused by breakages, in spite of the severe shock to each wheel on passing each crossing at full speed. For that matter, cast iron shells have been used very extensively here for target

practice, and they should be no more likely to explode in a gun aimed at a German than in one aimed at a board.

Light High-Conductivity Alloys for Air-Craft Engines. Because the weight of an engine which is to develop a given quantity of energy is inversely as its piston-speed, the little aircraft engines make an extremely great number of revolutions per minute. This, or more generally the lightness of the engines for the energy they develop, leads to an extremely great internal heat development per unit of weight, and hence of thermal capacity, and hence finally to a tendency of the engines to overheat. To meet this tendency these engines need material of great thermal conductivity as well as strength, so that the heat developed in them may escape readily, and not heat them so hot as to crack the lubricating oil, and thus choke them with carbon. Hence the use of the light high-conductivity copper-aluminum alloys of the duralumin class. Their chief value here lies in their combination of great thermal conductivity with immunity towards the embrittlement which steel suffers at about 300 C, rather than in their lightness, for none of them is as strong as steel per unit of weight.

These alloys were improved greatly during the war. The discovery of the best conditions for melting, alloying, and casting made it possible to increase the tensile strength required in the reception tests by nearly forty per cent. The regulation of the manufacture at the works of the Aluminum Castings Company was so close that only thirty castings in about ninety thousand were rejected, or at the rate of one in three thousand.

Stainless Steel for the Valves of Aircraft Engines. The tendency to overheat which we have just considered is exaggerated in the valves, because they are surrounded on all sides by the hot gases, and have so little chance to get rid of their heat by conduction that their temperature is said to reach 1000 degrees Centigrade (1832 F.), or above the melting point of these copper aluminum alloys. At this temperature most alloys of iron oxidize very rapidly. To meet these very try-

ing conditions an iron alloy called "stainless steel," of remarkable inertness and hence resistance to oxidation, was used. It contains about 13 per cent. of chromium. Before the war its resistance to oxidation, its "rustlessness," led to its rapidly increasing use for cutlery.

THE RÔLE OF
BIOLOGY AND MEDICINE
IN THE WAR

XV

THE FOOD PROBLEM

VERNON KELLOGG

IN his great book on "The Future of War," first published about thirty years ago, Jean Bloch, the Polish economist, said epigrammatically: Famine, not fighting; that is the future of war.

With due allowance for the combination of half truth and half exaggeration, characteristic of epigrams, this prophecy of Bloch's of thirty years ago was fairly realized in the World War. There was, to be sure, plenty of fighting in the war, but famine and the threat of famine played a very important part in its course and its decision. The food problem was almost dominantly insistent among the war-problems which all the major governments involved in the struggle had to face. The great diversion of man-power from the fields to the trenches and war-factories with the consequent lessening of food production, and an actual needed increase in consumption because of the transference of men and women from sedentary occupations to vigorous physical and fuel-burning activity, the transfer of horses and work-stock from the farms to the cavalry and transport service of the armies, the curtailed import of fertilizers, and the occasional actual destruction of food stocks during the military operations together with the military occupation and devastation of considerable areas of farm lands, all resulted in producing a food problem of great difficulty of solution. It meant a calling on external food supplies, and this at a time of unusual difficulties of transportation, to a degree never before dreamed of, and it meant a

voluntary or controlled modification of food habits and repression of food use by whole peoples beyond anything ever before attempted.

Dr. H. P. Armsby has recently most truthfully declared ("Yale Review," January, 1920): "The experiences of the great war have forced us to realize as never before that the maintenance of the food supply is the basal problem of civilization. Before commerce or manufacturing or mining can be carried on—before science or art or religion can flourish—man must be fed. A starving world cannot be made safe for democracy. Any rational program of national or international preparedness, not only for possible future war but especially for the hoped for victories of peace, must have as its prime element the maintenance of an abundant food supply at prices which shall adequately reward the producer and not unduly tax the consumer."

(There is then an ever-existent great national and international food problem: a problem that demands consideration in peace-time as well as war-time, although its insistence in war-time is enormously enhanced and made visible to every one.) In peace-time not many of us notice it, except in so far as it reveals itself by certain indications to our purses. Just now it is particularly a problem of the household budget: sufficient food exists, which may not be the case in war-time, but it costs so much that most of us are constantly worried by the effort to obtain it. So we appeal to economists for a solution of the problem. And these men in turn appeal to science to see if this all-resourceful last resort can do anything to help in the emergency. It therefore devolves on scientific food and nutrition experts, on men versed in scientific methods of food production and scientific guidance to wise and economical food use, to tell what they already know, and to try to know more, for the sake of the national well-being and the national strength. For national well-being depends largely on a sufficient and available food supply, and national strength depends largely on national well-being.

In the "relief of Belgium," as carried out by Mr. Hoover's Commission, we introduced into occupied Belgium and France, in the four years of the work, about five million tons of food stuffs of a value, at wholesale prices and with much unpaid service, of seven hundred million dollars. This food was selected with much regard to economy of purchase, ease of handling, keeping qualities, and, especially, concentration of food value in relation to weight and mass. The problem of transportation, during the period of the importations, was made so serious by the tremendous demand on shipping and the constant loss of vessels by submarines, that no waste stuff, possibly avoidable, could be carried.

The Belgian importations consisted chiefly of wheat and flour, dried beans and peas, animal and vegetable fats, condensed milk and sugar. These staples, with their small content of water and high nutritive value, best met the needs of the situation. Some meat, for protein needs, was available in the country, as were also some green vegetables and fruit. Out of these native and imported foodstuffs a ration, varying in character somewhat with season, and in amount with the varying situation as to money, actual food obtainable and conditions of transportation, was determined, and on it a great majority of the people lived. The wealthier ones could add to it by purchase of the limited native production. The poorer ones, those dependent on the American Relief Commission and the native relief organization for actual charity, had practically nothing else. At the end of the war practically one-half of the imprisoned Belgian and French population of nearly ten million people was living wholly or partly on charity. At one time actually one-half of the inhabitants of the great city of Antwerp was in the daily soup and bread lines.

Now this daily ration at no time was of character to produce much over two thousand calories. Three thousand, and even a fraction more, are considered by most physiologists to be the desirable minimum for the average man at reasonable work. Yet these Belgians and French maintained life, and most of

them a fair health, on much less than three thousand calories a day. To be sure, most of them did no heavy work, and many of them no work at all. There was little work to do, except for the Germans, and they would not do that. For the few actual heavy workers, the men in the coal mines, a supplement to the regular ration was given.

This ration also had a very low protein content as compared with the usually recommended one. It was only rarely that the protein food ran to as much as 50 grams: it was usually nearer 35 grams. The textbook rations usually call for at least 100 grams.

The lesson of the great nutrition experiment in Belgium is that a considerably lower ration than the one ordinarily recommended by physiologists can keep a people alive and most of them in fair health for a considerable period of time. Two elements in the experiment were unusual, namely, the number of subjects and the duration of it. On the other hand, the results of the experiment can be expressed only in large and general terms.

By the time America came into the war the demands of the Allies and European neutrals for importations of food had become so enormous, and the submarine warfare had so restricted the shipping available and made it necessary to limit its use to the shortest sea lanes, thus cutting out possibilities of bringing food from such distant sources as Australia, and concentrating the demand on North and South America, that the war food problem was more serious than ever. The already difficult transportation situation was made worse by America's need for tonnage for the sending overseas of her great army and its equipment in munitions, clothing and food. It therefore became evident that the use of food by the European Allies and neutrals would have to be repressed to the lowest safe amount. What was this amount for each country?

This was a problem for the English, French, and Italian governmental food controllers and for the American food administrator to decide. Theoretically a great pooling of Ameri-

can and Allied food supplies was made with a common attempt to place consumption at the lowest safe figure. England and France and Italy intensified their food control, restricting sales by dealers, using purchasing or ration cards, limiting the bills of fare in public eating places, and generally putting food use on a basis of governmental permission; while America, following a method presumably more in harmony with the spirit of our people, instituted under the stimulus and guidance of Food Administrator Hoover a nation-wide campaign of voluntary food-saving. This was reënforced by a considerable degree of official regulation of food manufacturers and wholesalers, but no attempt was authorized by Congress, in its food control act, to regulate the sales by retailers or the actual food use by individuals. As a result of a considerable increase in American production and the radical food-saving of the people, we were able to export to Europe during our first year after entering the war (April 1, 1917 to April 1, 1918) fifteen billion pounds of food, an increase of more than 200 per cent. over the annual average of late pre-war years.

The theoretical pooling of the available Allied and American food supplies made necessary the determination of fair allocations from the American surplus to each of the major Allied countries as well as to the European neutrals needing imports, the share of each to be based on the deficit between native production and a fair minimum consumption. This need of a proper division among needy countries led to the formation of various bodies for effecting the determinations, of which bodies one, known as the Inter-Allied Scientific Food Commission, was composed of representative food and nutrition experts from America, Great Britain, France, Italy, and Belgium, and had the responsibility for providing the food executives of America and the Allies with any scientific knowledge that might be advantageously used in making the determination of the food allocations.

This Commission held meetings at various times in 1918 and 1919 in London, Paris, Rome, and Brussels. One of its first

attempts was to reach an agreement on certain fundamental units and co-efficients necessary for use in determining the food needs of a large mixed population.

It is familiar knowledge that men engaged in different kinds of work, who might be classed as non-workers, light-workers, and heavy-workers, and women and children, do not all demand rations of the same value in calories. The Commission agreed that if the average man, doing medium work, is taken as the unit, then a child up to 6 years should have .5 of this ration, from 6 to 10 years, .7, from 10 to 14 years, .83, and girls above 14 years and women, .83.

In order to apply these co-efficients of conversion of all members of the population into "average men," so as to obtain the figure of the total quantity of food stuffs necessary for a given population, it is necessary to know the proportionate occurrence in the population of children, women and men. If the food necessary for a population entirely composed of average men be represented by the unit 1; then, on the basis of the distribution of men, women, and children in America and the Allied countries, England should receive .835, France, .845, Italy, .826, and America, .84. That is to say, every 100 individuals in England, taken in the proportions in which the different kinds of persons exist in the population, will be equivalent for feeding purposes to 83.5 average man.

The advisable daily ration for an average man was fixed by the Commission as one having a value of 3300 gross calories. By gross calories is meant the energy value of the foods as they are bought in the market. It was agreed that a reduction in 10 per cent. of this amount could be supported for a considerable time without injury to health.

With regard to the necessary protein content in a ration of this calorific value and made up of a number of different food stuffs it was agreed that such a ration would almost inevitably contain enough protein matter to meet the needs of the individual. At the same time the Commission records its belief that although meat is not a physiological necessity and hence

need not of necessity compose a part of this ration, and its place can be supplied by various other animal protein, such as milk, cheese, and eggs, and also partly by vegetable proteins, nevertheless, the dietary habits of the nations of Western Europe being what they are, it is highly desirable to include a certain proportion of meat in the ration of any people long accustomed to its use.

As regards fat, the Commission agreed that a desirable minimum of fat would be 75 grams a day. It recommended that this fat ration be composed primarily of vegetable fats and if there is an insufficiency of these available, the deficit should be made up by animal fats.

For the special rations in the army and navy it was agreed that for the troops, both naval and military, behind the fighting lines, the minimum rations should be that of the "average man," that is to say a ration to produce 3300 calories and containing at least 75 g. of fat. For the actual combat troops the value of the ration should be increased by 600 calories and the fat content by 25 g. For troops fighting in high mountains the calories should be further increased to the extent of 200.

The Commission discussed at much length the subject of the milling rate, or rate of extraction, of flour from grain. The usual extraction rate for bread grains in practically all countries is considerably below 100 per cent. That is to say, from a given amount of wheat or rye or other grain, anywhere from 50 to 85 or 90 per cent. of the berry goes into the flour, the rest, which is composed chiefly of the outer coats of the berry, composing the "offals," or "roughage," which is mostly fed to animals. When there is need, however, of "stretching" the grain, the extraction rate is raised until it may, as in actual whole wheat flour, be composed of all of the grain. This means that the flour contains a certain part, even up to all, of the offals normally kept out of the flour. The question is, what is the highest extraction rate that may be advisably used, from a physiological point of view, at times when there is a shortage of grain, in order to obtain as large

an amount of bread as possible from the grain available. Taking into account all of the knowledge available from scientific experiment, the Commission agreed that for the sake of the general health of the whole population it is advisable not to use a higher extraction rate for wheat than 85 per cent., for rye than 70 per cent., for maize 85 per cent., and for barley, 65 per cent.

At the same time that the Inter-Allied Scientific Commission was considering the international food problem from a scientific point of view the United States Food Administration, endeavoring by all means in its power to effect a material saving of food in America for the sake of being able to send as large an amount as possible to the Allies, whose very persistence in their war effort depended upon these American food contributions, was paying much attention to disseminating information among the people concerning wise and economical food use. This involved many recommendations based on scientific knowledge of a proper balancing of the dietary and the possibility of substituting certain kinds of more abundant foods for those less abundant but necessary to the Allies. For the sake of having the best scientific information available in connection with this propaganda the Food Administrator asked a large group of the leading physiological chemists and food and nutrition experts of the country to act as an advisory committee on food and nutrition, and all questions whose answer involved a reference to scientific knowledge of food use were referred to this committee. As a result of this arrangement much recent and not yet popularly understood knowledge of food science was disseminated among the people.

In addition to a general popular propaganda of scientific food knowledge the Food Administration gave particular attention to encouraging the teaching of food knowledge in the public schools and colleges and universities of the country. There were issued under the auspices of the Food Administration several textbooks on food compiled by competent au-

thorities and made widely available to the school children and college students of the land.

In September, 1917, a conference of representatives of the American Navy, the offices of the Surgeon-General and Quartermaster-General of the Army, U. S. Food Administration, the Bureau of Chemistry of the Department of Agriculture, and the Medical Department of the Council of National Defense, was held in Washington "for the purpose of considering questions relating to the subsistence of the army."

✓ In this conference some of the best American authorities on nutrition voiced the opinion that the garrison ration of the U. S. Army provided much more food than would seem to be required except for very heavy muscular work under rather severe conditions of weather and climate. Contrary opinions were, however, expressed by officers of the army who had had much experience in small organizations without army ration. The representatives of the Food Administration also referred to the many complaints that had come to them from civilians visiting the army camps, so far established at that time, of an enormous wastage of food to be seen in those camps. The discussion of these and other points in the methods and character of the army feeding led to the determination to have a series of nutritional surveys conducted by experienced observers in the several army camps with a view to determine quantitatively the actual consumption and the actual wastage of food.

Early in September, 1917, there was organized a Food Division of the Surgeon-General's office which was later established by the War Department as a Division of Food and Nutrition of the Medical Department of the Army. Major (later Lt.-Col.) John R. Murlin, of the Sanitary Corps, a well-known nutrition expert, was very active in all this work and from various official reports and scientific papers published by him and his associates, a large number of facts concerning army feeding and rationing in general have been made generally available.

The method of conducting an army nutritional survey was in brief as follows: A survey party, reporting to the commanding officer, usually spent the first few days in becoming acquainted with the camp and in learning where typical messes could be found. The most highly efficient as well as the poorest messes were purposely avoided. During these first few days there was also made a preliminary inspection of the subsistence stores and of the food on hand at the mess houses. Next a determination was made, consisting of careful inventories, by weight, of all foods in the store room in the beginning and at the end of a definite period and of all accessions to stock during the period. At the same time the garbage was carefully separated into edible and inedible portions; the former was weighed, ground through a meat grinder or chopped with spades according to the amount, and a sample taken for analysis. Any foods whose composition was in question were likewise analyzed. Deducting the second inventory from the first, plus accessions to stock, and reducing to protein, fat, carbo-hydrate, and energy content, and finally subtracting protein, fat, carbo-hydrate, and energy content found in the edible waste, the net consumption for food per man per day would be calculated.

It was found by a careful study of 427 army messes representing about 135,000 men, that although the daily ration supplied had a fuel value of about 3900 calories the actual consumption of food amounted to a little over 3600 calories per man. The protein content amounted to 131 gr. supplied and 122 gr. consumed; the fat content, 134 gr. supplied, 123 gr. consumed; the carbo-hydrate content, 516 gr. supplied, 485 gr. consumed. The total waste was 7 per cent. In addition to the ration almost all of the men added to their daily food intake by purchases made at the canteens, most of the additions consisting of chocolates, cakes, pies, and soft drinks. The average consumption record for 261 canteens was 365 calories per man per day.

After careful analysis of the make-up of the ration in vogue

in the army it was decided to formulate a new ration to be called the "training ration" which was especially worked out so as to avoid the considerable waste which occurred in connection with the old ration. This "training ration" provided for a protein content of 127 gr., a fat content of 135 gr. and a carbo-hydrate content of 575 gr., giving a total fuel value of 4132 calories. This new "training ration" was considerably in excess of the rations in vogue in the British, Canadian, French, and Italian armies. The British Home ration for May, 1918, provided 3483 calories; the Canadian ration for July, 1918, provided 2946 calories; the French normal ration for March 29, 1918, provided 3604 calories; the Italian Territorial for February 1, 1917, provided 2797 calories.

Elaborate studies were made by the War Department's Division of Food and Nutrition on the effect of season on food consumption, on the actual consumption of food as effected by the length of time in camp, on the food consumption in the army compared with other occupations, and on the variations in waste and strength of the men in relation to their food consumption. Many of the facts and statistics thus found out will be of great value in the future wise determination of the American Army ration as well as in their significance for mass feeding generally.

However, this work only throws light upon the feeding of men of certain conditions of age and physique. There is quite as necessary a further scientific knowledge of the proper feeding of women, adolescents, and infants, both as mass feeding and individual feeding. (The experiences of the war have created a special interest in this problem and the people are ready, as perhaps never before, to take an interest in an investigation of the problem and to listen to, and make use of, the results of such an investigation.) Therefore, the National Research Council, solicitous to encourage all scientific investigation, especially such as may have an immediate value in the maintenance and increase of the national well-being, has organized a special committee on food and nutrition in connection

with the work of its Division of Biology and Agriculture. This Committee is composed of a number of leading physiological chemists and food and nutrition experts of the country and has laid out an important program of investigation. The results of this work should be of the highest value to the nation.

XVI

THE WAR SERVICE OF THE MEDICAL PROFESSION

FREDERICK F. RUSSELL

THE DEVELOPMENT OF THE PERSONNEL OF THE MEDICAL CORPS OF THE ARMY

THE number of medical officers in the army before we entered the war was, on June 30th, 1916, 589, and this number was made up of 443 belonging to the regular army and 146 who were members of the Medical Reserve Corps. On June 30, 1917, one year later, and two and one-half months after war had been declared, the prompt response to the call for physicians from civil life to assist the small nucleus already in service, resulted in an increase to 4125, of whom 487 belonged to the regular service and 3636 to the reserve. On June 30, 1918, there were 867 regular medical officers and 20,855 who were serving with temporary commissions in the Medical Corps, a total of 21,722. On June 30, 1919, there were 948 regular and 11,783 temporary medical officers, a total of 12,731.

The greatest number in service was 989 regular and 29,602 temporary officers, a total of 30,591 about the middle of November, 1918.

The enlisted force of the Medical Department increased from 6691 on April 6, 1917, to 154,556 on July 1st, 1918, to 264,181 on November 15th, 1918, and decreased to 98,396 on June 30th, 1919. Until the time of the last reorganization of the army, in 1909, the enlisted men of the Medical Department were known as the Hospital Corps, a name far from appro-

priate, since large numbers of them were attached to mobile military formations, companies, battalions and regiments, and they had no hospital duties whatever while so serving; further it was a corps without officers which was an anomalous condition and for these and other reasons the name was changed to the enlisted force of the Medical Department; the latter also comprised the Dental, Veterinary and Nurse Corps, and after the outbreak of the war, and the passage of the National Defense Act, the Sanitary Corps, the U. S. Army Ambulance Service and a large number of Contract Surgeons and civil employees.

These elements of the Medical Department and their strength at different periods is shown in the following table:

In 1918, there were, in the whole United States, 147,812 physicians, and among these there was a considerable number who were not in active practice of their profession. The largest number on active duty with the army on any one date was 30,591, on the 15th of November, 1918. There were many losses among the medical officers; for example, in some weeks the losses exceeded the gains, so the total number of physicians who were at one time or another in active service was much greater than the number just given. The exact figures cannot now be stated, but it was in the neighborhood of 40,000, and this last number represents, perhaps, about one third of the physicians in active practice in the United States.

It has been estimated by military authorities in the past that it would require seven physicians per thousand of army strength for service directly with troops and approximately three per thousand in addition for work at home with recruiting, with convalescents and chronic cases. Since we had approximately four million men at one time or another and about 40,000 physicians in all, the result, 10 per thousand, corresponds very closely with the estimate. The greatest number in the army at any one time was 3,634,000 on the first of November, 1918, and at about that time we had 30,591 medical officers, which again is very close to the estimate.

STRENGTH OF PERSONNEL, MEDICAL DEPARTMENT

A. Increase in Strength of Personnel

Strength when war was declared and greatest number in service (about Nov. 15, 1918) ; also July 1, 1918, and June 30, 1919.

	Apr. 6, 1917			July 1, 1918			Nov. 15-30, 1918			June 30, 1919		
	Regular	Temporary	Total	Regular	Temporary	Total	Regular	Temporary	Total	Regular	Temporary	Total
Medical Department:												
Commissioned	491	342	833	867	20,096	20,963	989	29,602	30,591	948	11,783	12,731
Enlisted			6,619			154,556 ¹			264,181 ¹			98,396 ¹
Dental Corps: Commissioned...	86	0	86	211	2,746	2,957	229	4,391	4,620	220	1,999	2,219
Sanitary Corps: Commissioned...	0	0	0	0	1,389	1,389	0	2,919	2,919	0	1,817	1,817
Veterinary Corps:				118	1,429	1,547	115	1,887	2,002	112	905	1,017
Commissioned	62	0	62									
Enlisted	0	0	0	97	11,543	11,640			17,160			
Ambulance Service:												
Commissioned	0	0	0	0	168	168		209	209	0	111	111
Contract surgeons		181	181	0	120	120				0	42	42
Army Nurse Corps	233	170	403	2,000	10,186	12,186	3,524	17,956	21,480	2,084	7,532	9,616
Civilian employees			450			9,238			10,695			5,820

¹ Including enlisted Sanitary Corps.

B. Changes in Regular Medical Corps

	Major General	Brigadier General	Colonel	Lieutenant Colonel	Major	Captain	Lieutenant	Total
June 30, 1918....	1	0	64	112	296		394	867
June 30, 1919....	1	2	60	109	349	154	264	939
Losses:								
Deaths	0	0	0	0	4	0	5	9
Resignations ..	0	0	0	0	5	2	21	28
Retirements ...	1	0	7	1	2	1	0	12
Discharges ...	0	0	0	0	0	1	3	4
Declinations ..	0	0	0	0	0	0	20	20
Other causes ..	0	0	0 ²	0	0	0	0	3
Appointments ...	0	0	0	0	0	0	145	145

² Col. Ireland made Surgeon General, Col. McCaw made brigadier general, and Lieut. Col. Noble made brigadier general.

	Regular	Temporary
Aug. 1, 1918: ³		
Overseas	301	7,698
United States	365	14,963
Total	866	22,661
June 30, 1919:		
Overseas	338	6,217
United States	603	5,578
Total	941	11,795

³ Figures for July 1, 1918, will not be known until the records of the chief surgeon, American Expeditionary Forces, are transferred to the Surgeon General's Office.

The response of the medical profession to the call of the Government was at all times sufficient for our needs, and in addition permitted us to loan medical officers to our Allies in considerable numbers, particularly to Great Britain.

The wastage or losses from all causes during the period of our participation in the war, was about ten thousand or one-quarter of the total names on the rolls.

SANITARY ENGINEERING PROBLEMS AT HOME AND ABROAD

In home territory in all large National Army and National Guard camps good potable water was provided, where possible by purchasing treated water from a nearby city, but when this was not feasible a complete water supply system was installed at the camp itself. This usually consisted of an impounding basin for the collection and sedimentation of the raw water, which was then filtered in some form of rapid sand filter after dosing with alum or other suitable coagulant, to throw down all suspended matter. Finally, at practically every place, the clear water was then treated with anhydrous chlorin gas, which disinfected the water by oxidizing all organic matter.

In smaller places, the question of water purification was less satisfactorily answered. The Lyster bag method of chlorination was the standard. The chlorin was added to the raw water, in the form of bleaching powder, which was put up in small measured quantities, in glass ampuls. The bag itself is made of strong canvas and is attached to a folding iron ring at the top. At the sides a little above the bottom, high enough to avoid the sediment which falls gradually to the lowest point, are several simple faucets from which the water is drawn off to fill canteens and other pure water containers.

The control of successful water sterilization by means of chlorin is fortunately a simple matter, consisting merely in a test for free chlorin by means of the starch iodine test. This is made thirty minutes after the bleaching powder has been added to the water in the Lyster bag, by taking a large cupful and adding to it 10 drops of a 10 per cent. solution of iodide

of potassium, and the same amount of a one per cent. solution of soluble starch and one-half per cent. of sulphate of zinc. If free chlorin be present, the iodine is liberated from the potassium iodide and it combines with the starch, giving the characteristic blue color of starch iodide. The significance of the test is clear when it is realized that the chlorin is used up by the organic matter present in the water, and that there can be no excess unless all the organic matter has been oxidized. If the test shows no free chlorin more bleaching powder is added until some is present in excess.

The principle of chlorination in the Lyster bag is the same as in the largest installations, depending as it does on the oxidation of all organic matter, by the oxygen set free by the action of nascent chlorin on the water molecule. The small quantities treated in this method make it very difficult to adjust the chloride of lime accurately, and the result is that the water may be overdosed with chlorin, giving it an unpleasant taste. The soldier may then be tempted to drink untreated water, which although clear, bright and sparkling, may be heavily contaminated with pathogenic bacteria, rather than the water which is quite safe but less attractive in appearance and flavor.

In the A. E. F. both large and small scale water treatment was used almost everywhere the American troops were stationed. In the back areas, that is, on the Lines of Communication, or rather, in the area of the Service of Supply (S. O. S.) as it later came to be called, it was usually possible to use the large scale methods in coöperation with the French civil and military authorities.

Chlorination of water supplies in the United States has been customary for the past ten years, but until 1917 the method was not known in France. It was introduced there by an army chemist and water supply expert, who had been selected for special work in France by the National Research Council. This officer worked with the French authorities and at the Laboratory of the Museum de Histoire Naturelle, Paris, in conjunction with a French chemist he carried out a series of

demonstrations showing the practicability of treating successfully the raw water of the Seine. The results of these trials were published in the "Revue d' Hygiene," 1918, and reprints of this article proved of great assistance in obtaining the ready coöperation of French municipalities for the chlorination of their public water supplies.

As one area after another was taken over for billeting and training American troops, complete sanitary surveys were made, including a study of the quantity and quality of all available water supplies. Until the results of the survey were known and posted all water was treated as if contaminated and was chlorinated.

In the front areas, where it was impossible to deliver safe water at water points for men and animals, by means of large motor trucks, recourse had to be had to the Lyster bag. Each organization was equipped with these bags and the necessary bleaching powder, and a water detail, consisting of one or more men of the command, was in charge of the water purification. Satisfactory results were not usually obtained unless the water detail consisted of men permanently assigned to this work under the direction of the surgeon of the command.

The process of chlorination, when used with reasonable care, either on a large or small scale, is one of the most successful methods of purifying water, and its adoption for military expeditions is a matter of the greatest importance for the health of the troops. Had it been possible to use it everywhere as planned we would have escaped the relatively small amount of typhoid fever and dysentery which did occur in France. The difficulties of transportation under war conditions on the western front were such that it was impossible at all times to have adequate supplies of bleaching powder in the hands of the troops, and they were thus compelled to drink whatever water was available. Early in 1918 the system of supply was changed so that bleaching powder was issued with the rations of the man. This was a decided improvement, but lack of trained personnel and the inexperience of many of the troops

made them careless in the enforcement of water discipline. Nevertheless, the total number of cases of diseases of the intestines, diarrhoea, dysentery and typhoid was smaller than in any other war in history.

SELECTIVE SERVICE — *again*

Another considerable medical activity of the war was centered in the Selective Service Boards which were organized by and administered under the direction of the Provost Marshal General. It was expressly stipulated in the Selective Service Law, that the machinery should be civil rather than military, and no officers of the army engaged directly in the selection of the men who were to make up our forces. A few of the administrative heads of the service, however, were members of the permanent or temporary military force. This was particularly true of the federal control of the service, which centered in the office of the Provost Marshal, General Crowder, who, in times of peace, is the Judge Advocate General of the Regular Army; some of his assistants belonged to the same body. In each state, the governor, under the law, divided his territory into districts, one for each county, except in cities of over 30,000 population, and these were divided into districts of not over 30,000. This meant the organization of 4557 local boards, each consisting of three men, of whom one was a physician who made the physical examinations, sometimes alone, but often with assistance. Under the first draft the number of men selected by the Local Boards was 527,000. On November 8, 1917, new selective service regulations were promulgated which authorized the regular appointment of assistant medical examiners for the Local Boards, and also of a new board, composed entirely of physicians called the Medical Advisory Board, on which all the special fields of medicine were represented by experts. To this Board all doubtful cases were referred by the Local Boards; in all there were 1319 such Advisory Boards, distributed through the states so as to be most easily accessible. As a rule they were located at some

well equipped hospital, where facilities were at hand for the most intricate tests and specialized examinations. Under the first selective service act, approximately 10,000,000 men, from 21 to 30 years of age, were registered, and of these 2,510,000 were examined by the Local Boards. Of this number 730,000 or 29.1 per cent. were rejected on physical grounds.

The report of the Provost Marshal General indicates that about 22 per cent. of the rejections were caused by some mechanical defect in the organism, or rather some defect or disease that would interfere with its mechanical performance, such as defects in the bones and joints, flat foot and hernia. An additional 15 per cent. were rejected because of imperfections of the sense organs, and about 13 per cent. for defects in the cardio-vascular system. About 12 per cent. were rejected on account of nervous and mental troubles, in part due to abnormal thyroid secretions. About 10 per cent. were rejected on account of the two communicable disease groups — tuberculosis and severe cases of venereal infections. About 8½ per cent. were rejected because of developmental defects in physique; about 6 per cent. because of diseases of the skin and teeth, and about 13½ per cent. for miscellaneous defects.

The significance of these findings for civil life is not immediately apparent. The demands of the military life on the physique of a man are much greater than those of civil life, because of the need for ability to make long marches while carrying a heavy load (40 or more pounds) and for reserve strength and vitality to throw into a fight at the end of a long and wearisome march. A man who weighs only 100 pounds, however healthy and however strong he may be for his size, can rarely do this. Yet his small size may even be an advantage in civil life. Again, many a man with a tendency toward flat-foot or hernia may do his work in civil life well, and always have excellent health, and be really unaware of any weakness, but his presence may handicap combatant troops. Defects in sense organs are less important in civil life, because the individual adjusts his life to them and finds ways to pro-

tect himself. Also the stress of struggle, work and excitement on the battlefield requires a degree of perfection in heart action and innervation that is rarely demanded in civil life. On the other hand, the disabilities due to nervous and mental diseases and to tuberculosis and the venereal infections are an equal handicap in the life of a civilian. Considering these circumstances it is probable that not over half of the 29.1 per cent. rejected for military service were incapacitated in a civil sense.

CASUALTIES FROM POISON GAS

When looked at from one point of view poison gas is one of the most humane weapons of warfare. Although 74,779 of the 274,217 battle casualties resulted from gas, the number of deaths was very small, 1.87 per cent., as compared with 23.4 per cent. from shell and bullet wounds. These figures indicate that a man suffering from poison gas has twelve times as many chances for recovery as a man put out of action by other weapons.

In the early days of the war chlorin gas alone was used, being liberated in great clouds when the direction of the wind was favorable, from steel cylinders of liquefied chlorin, and the cloud was carried by the wind in the direction of the enemy. Experience soon demonstrated that the poison gas was quite difficult of control when used in this way, and the chlorin cloud gas offensive was soon superseded by gas of many sorts contained in explosive shells which could be placed exactly where the enemy desired. Reference to other portions of this work will give greater details of the methods of using gas. Our interest at this moment lies in its medical aspect alone.

The new gases were of many sorts, but the most important was dichlor-ethyl-sulphid or mustard or yellow cross gas as it was commonly called. The liquid gas vaporizes rather slowly on the explosion of the shell, and in addition the fluid itself is sprayed over all those in the immediate neighborhood of the explosion. Its effects are not noticed at once, and are really not much appreciated until about four hours after ex-

posure. It causes an eruption on the skin, at first of larger or smaller rose red areas, which will later form blisters containing yellow fluid. Later the fluid may coagulate and become infected and the mass will slough away leaving a large punched out ulcer. As the fluid from a blister runs over the skin it may produce secondary eruptions and even ulcers. In addition to the lesions on the skin, there may be conjunctivitis, and ulcerations of the cornea, and a little later vomiting, hoarseness, cough and pain with shortness of breath; in the severer cases there is œdema of the lungs and early death. Cases of intermediate severity may progress well for a day or two, and then develop a broncho-pneumonia from secondary infections through the damaged mucous membrane of the respiratory tract. Such cases die or recover, depending upon the extent of the lesion. As a precautionary measure it was customary to consider all gassed men as litter cases, to be carried to the rear to special gas hospitals after receiving first aid treatment, which usually consisted of irrigations of the eyes, nose and mouth with a five per cent. solution of sodium bicarbonate, and an application of soft soap or of soda solution to the body, or if the case be seen early enough a two per cent. solution of chlorinated lime may be used to neutralize the gas. To reach the throat, trachea and the bronchi, inhalations of aromatic spirits of ammonia, or of two per cent. sodium thiosulphate or 0.5 per cent. sodium bicarbonate were used. The further treatment of the skin lesions was much like that employed for ordinary burns. As soon as possible the man's entire clothing was changed, as the gas adhered to it and remained active for long periods, and he was given a complete bath in warm water and alkali and a complete new outfit of clothing.

The gas inhalation cases which were severe enough to be sent back to base hospitals were treacherous and uncertain in their course, and many died after an illness of weeks. All possible lesions of the lung were present from simple catarrhal bronchitis and œdema to suppurative processes involving the trachea and bronchi and the lung itself. In the slower but

severe cases the inflammation might gradually extend from one part of the lung to another over a period of two weeks or more, the patient becoming gradually more and more cyanosed and water logged.

The treatment subsequent to the first aid already described consisted in absolute rest in bed, occasional bleeding, and occasional administration of oxygen, often for long periods, and the proper amount of stimulation, and the interval administration of alkalis, and for the conjunctivitis and skin burns, alkaline applications and irrigations. The strain on the heart was often severe requiring the exhibition of digitalis. Small doses of morphine were necessary to control the cough and to secure rest. The sputum was often purulent and streaked with blood, and in some cases profuse and watery. The hoarseness was sometimes followed by complete loss of voice and examination usually showed œdema and swelling of the vocal cords or ulceration and the presence of a false membrane. If the pharynx was also involved there was pain on swallowing, with dryness and a burning sensation in the nose, throat and mouth. The pain in the chest was a frequent symptom, occurring in perhaps 75 per cent. of the cases, and while it was not limited to any region of the chest it was more common over the heart than in any other location.

During convalescence a system of graduated exercises was used to restore the men, if possible, to complete recovery, before returning them to a duty status.

Insufficient time has elapsed to enable us to know the end results of gas poisoning. So far as one can tell at the present time, from the physical examinations of thousands of returned patients, there is no reason for believing that the irritation and subsequent inflammation of the respiratory organs tends to induce tuberculosis or to light up a focus of pulmonary tuberculosis already existing.

Further, the evidence is scant that among returned soldiers, at least, there is any material destruction of the tissue of the lungs.

RECONSTRUCTION WORK IN HOSPITALS

The development of reconstruction work in army hospitals has been one of the strikingly good results of the war. The idea is not altogether new, but it, like so many other advances in medicine and surgery, had, before the war, been confined to a certain few hospitals of the best class, and it also was of very unequal quality. The development during the war in this field consisted in applying the best features of the work to all our hospitals, in a standardized manner.

The so-called reconstruction work was really divided into two quite different sorts of undertakings, although they both went along side by side, usually using the same methods and principles, but with two separate and distinct objects in view. The first was to occupy the man's mind and at the same time to improve it, so that his spirits and morale were not impaired by his long and possibly painful illness. (The purpose of the morale treatment) was to overcome the condition so long known as hospitalism, a form of chronic invalidism which leads to helplessness and loss of initiative, which is entirely mental and has no relation to the amount of physical deformity or of limitation of function. (The second object is the restoration of function of the injured part as completely and as early as possible.) To accomplish these results, which are as a matter of fact, just as important in civil life as in military, it was found that the reconstruction work could not be postponed until the patient was sufficiently recovered to be sent to another hospital especially set aside for this sort of teaching, but that it must be started just so soon as the patient was able to do anything at all, and that, therefore, every hospital where patients were sent for anything more than emergency treatment must have a "reconstruction staff" in addition to the medical and surgical staff. These persons, sometimes physicians, but more often teachers or psychologists, went into all the wards and started instruction as soon as a patient was able to do anything; as, for example, a man might be taught to do bead work simply

as a means of arousing his interest and causing him to think of the possibilities for retraining himself for some new form of employment suited to his modified physical condition. Whenever possible the new work chosen was on a higher plane than his former occupation. For example, a house painter might be taught fancy lettering and sign painting, which required less strength but more skill, and some have been able to command higher wages after injury than they had been able to obtain before. Blind men were taught to assemble watches or clocks or intricate automobile parts, and so to support themselves at least as well as before entering the service of their country. (The training was both vocational and therapeutic and the two were inseparable.) A barber, for example, who had received a considerable injury of the hand would recover the lost function quicker in doing the work of a barber than by long hours of passive or mechanical motion in the hospital ward. The difference in the spirit of the men was soon seen and in its turn exerted an undoubted influence in hastening convalescence and in preventing the paralyzing hospitalism which formerly followed injuries which interfered with the earning power of the individual. Such injuries are common in civil life, in the industries and in mining and railroading and civil hospitals and insurance commissions will no doubt continue to use the reconstruction methods which have been elaborated during the war. The public, the patient and the physician now are all informed of the great possibilities of corrective vocational training and will demand its use in the future.

XVII

SOME DISEASES PREVALENT IN THE ARMY

FREDERICK F. RUSSELL

THE WAR NEUROSES

THESE diseases early in the war came to be called "Shell-shock" and a considerable amount of literature and discussion has grown up about them. Although the forms of psycho-neuroses which appeared early were apparently new, it was soon recognized that the disease was essentially an old and well established entity, but that the manifestations of the diseased condition took on new forms peculiar to the war. In times of peace we have comparable conditions resulting from railroad and other accidents; in fact from anything which makes a profound mental impression, usually associated with great apprehension, fear or horror. Even in our training camps in this country, three thousand miles away from exploding shells, many cases of war neurosis developed. One of the commonest forms was stiffness of the spine and rigidity of the muscles of the back, usually in some markedly flexed or twisted position. Although the manifestations of the disease were innumerable they all had one feature in common: complete impossibility of performing the full duties of a soldier in the front line of the armies. It is not understood that these men were malingering, that is, faking a disability, because the man himself, unless given the proper care and treatment, was quite unable to control the malady. In other words, his symptoms were due entirely to his nervous and highly excited mental condition, and they had no organic or actual tissue

change in the body as a foundation. The conditions under which the men fought were enough to shake the nerves of all but the strongest individuals, and it is not to be wondered at that a profound impression was made on any person in the least inclined to be emotional. The symptoms of the disease were so numerous that it is impossible even to enumerate them, as almost every known disability was mimicked.

Early in the war the purely nervous nature of the conditions was not recognized by the physicians in charge of most of them, nor by the public, and the men were treated in the base hospitals as though they had a serious organic lesion in the brain or spinal cord, rather than a pure disturbance of function without organic change. As the patient was still in an emotional and highly sensitive state each suggestion of disease soon became to him a reality, and as time went on the course of the disease grew worse, rather than better, and chronic invalidism became the only outlook.

When, however, these cases were carefully studied by trained neurologists their identity with peace time neuroses was established and a complete reversal was instituted. This occurred at a very early date among the French, who have long been foremost in the knowledge of the psychoneuroses. The patients were no longer sent home or even to the base ports, but were treated in special hospitals not far back of the front, by men who were especially skilled in nervous diseases. The treatment was along definite lines, was firm, almost paternal, and above all was given promptly, as soon after the true nature of the disease was recognized as possible. In principle the successful method of treatment was essentially reëducation in the life of a soldier. Drill and work of a useful kind was kept up as much as possible and everything done to aid the patient in regaining his normal healthy view of the life of a soldier and his control of his emotions. In the military atmosphere of drill and useful work and with good hygiene, food and comfortable living conditions it was astonishing how soon these men became normal soldiers again, and although many were unable to resume full

duty in the front line again they did their part somewhere in the rear, in the Service of Supply of the armies.

It had been estimated, early in the war, that about 10 per cent. of cases admitted to hospitals in the A. E. F. were of this nature, and that about 60 per cent. of these had been returned to duty. It was also frequently noted that a neurosis rarely occurred in a wounded man, and that they were exceedingly rare in colored soldiers. It is doubtful if these were so numerous as that, for there were only 3795 cases reported as such during 1918, and even if 4266 cases of hysteria are added the sum would be only 8061 out of a total of 82,289 diagnoses reported during the year. On the whole, the American Army was relatively free from these conditions, and this was due principally to the fact that we profited from the experience of our Allies and excluded from the ranks of our army as many as possible of these who would be more liable to develop such neuroses. At each training camp and mobilization center was stationed a board consisting of one or more psychologists and psychiatrists, and, as a result of their examinations of the recruits as they arrived from their homes, all the weak-minded, mentally diseased and the neurotic were eliminated. This not only reduced the number of cases of war neuroses, but also kept down our military offenders and criminals. No army in history was so free from crime, both large and small, as the American Expeditionary Force.

INFECTIOUS DISEASES DURING THE WAR

In the study of the infectious diseases, one of the fundamentals is the problem of the healthy human carrier. In the ordinary course of events a person who is infected with some pathogenic organism develops the particular disease caused by the microorganism in question, and he exhibits a more or less typical picture of the disease, and either recovers or succumbs from the infection. If he succumbs we can often demonstrate the presence of the causative microorganism in the blood and in many of the tissues at autopsy, often in enormous numbers. If

the patient recovers, the conditions are quite the opposite, the causative organism, after the height of the disease is passed, tends to disappear from the blood stream and then from the body, and in most infections it is necessary to make the usual bacteriological examinations early in the course of the disease in order to be successful in isolating it. Sooner or later, therefore, there comes a time when the infecting organism is unable to survive in the combat with the defensive forces of the body, and it disappears completely. We know, however, that there are many mild cases in all the infectious diseases, from which, nevertheless, the specific organism may be recovered. Here, also, the germs usually disappear completely with recovery. The next step, from the mild case to the healthy carrier is an easy one; at first glance it sounds paradoxical to speak of this condition as an infection because there are no symptoms of illness. Yet, if we accept the presence of immunity to a new infection and of specific anti-bodies in the blood as evidence of the invasion of the body we must consider the healthy carrier as a person who suffers from the mildest form of infection. Even in this case the normal course of events leads to the gradual disappearance of the infectious agents from the body and the usual healthy carrier is merely casually or temporarily in that condition.

In certain persons, however, the organism continues to exist in the body for an indefinite period, sometimes for years or even for the remainder of his life, and he is then classed as a chronic carrier from whom the pathogenic organism can be obtained either constantly or at intervals.

The temporary carrier frees himself from the invading bacteria by developing an immunity with a surplus of anti-bodies in his body fluids sufficient to kill off the invaders. Why does this not occur also in the chronic carrier? Is the difference due to the microörganism or to the host? Many investigators have examined the bacteria isolated from such cases, without being able to establish any regular or constant peculiarity of carrier organisms. They seem to vary in the same way and to the same

extent in their cultural and serological reactions and in their virulence for animals as do cultures isolated from frank cases of disease.

On the other hand, it is possible oftentimes to find differences in the host, as in the case of typhoid carriers, cholelithiasis, or some other disease process in the gall bladder is commonly present. In the case of diphtheria carrier abnormalities in the tonsils are common. We find, therefore, that the weight of evidence is to the effect that a person becomes a chronic carrier because of some more or less well-marked organic pathological lesion in his body, and in this abnormal tissue the invading organism finds favorable conditions for a purely parasitic existence.

It was due to the presence among recruits arriving at our camps of temporary and chronic carriers, as well as cases, that one after another of the acute infectious diseases developed sooner or later among most of our troops. All of the diseases of childhood, measles, mumps, scarlet fever, and also smallpox, typhoid, dysentery and malaria were all introduced repeatedly, yet only the first spread, as we had no method of rendering soldiers immune to infection by vaccination as we did in the case of smallpox and the typhoid fevers. Except for their presence in such large numbers and their complications, there was nothing of interest in these diseases. A few of the rarer infectious diseases are of more interest and they will be briefly discussed. Trench foot was distinctly a war disease, and was due to the unnatural environment in which troops were placed because of the remarkable development of the system of trench warfare. That it is preventable is now generally accepted, and we suffered relatively little from it, because our men saw comparatively little of trench warfare, and because of the lessons learned from the experience of our Allies. It consists of more or less damage to the skin, the underlying soft tissues and blood vessels of the feet and legs from prolonged exposure to wet and cold in tight or ill-fitting boots and shoes. The skin is bruised, the soft parts and the blood vessels are constricted

so that the circulation is ultimately shut off from the distal part of the extremity. With the failure of circulation and the possibility of infection through the damaged skin, a condition of dry or moist gangrene develops which leads to serious infection or to spontaneous amputation of the affected part. Operative procedures were always necessary to secure a clean stump and to prevent the spread of infection up the limb. The largest number of cases in the American Army occurred during the Argonne-Meuse offensive of October and November, 1918, when the troops were fighting continuously day after day and week after week in the rain and mud and in temporary trenches, and in situations where it was impossible to provide them with dry foot wear or to relieve them long enough for them to dry out their own. In 1918 we had 1715 cases reported, giving a rate per 1000 of 0.68. The total deaths from this disease, however, were only five. Trench mouth is another new term which sprang into use because the facilities for careful and scientific examination of new cases were not available. The symptoms were those of sore mouth, shown principally by red, tender and bleeding gums, with more or less involvement of the tonsils and the mucous membrane of the cheeks. The lesion was, therefore, an ulcerative and sometimes pseudo-membranous inflammation of the mucous membrane of the mouth and gums. The corresponding lesion of the tonsil had long been known as Vincent's angina, and that condition is always associated with the presence of the spirillum and fusiform bacillus of Vincent. In these cases of sore mouth the same microorganisms were found to be regularly present. Whether they are the primary cause or merely secondary invaders is not well established, nor is the manner of the spread of the disease well known. It apparently spreads by contact from soldier to soldier from common eating utensils, and possibly from pipes or contaminated articles of food. The position of the troops in the front areas, particularly in the trenches themselves, made the ordinary principles of mouth hygiene impossible of execu-

tion and what might have been slight infections under ordinary conditions became serious ones.

The disease yields readily to treatment and as soon as a man could be sent to the rear to a dentist he could soon be cured by local applications of dyes and caustics.

The disease was serious, not because of the deaths, for there is practically no mortality, but because it produced a considerable number of invalids, each requiring care and treatment from the medical personnel. The disease is not a new one, and there is no justification for the term "Trench Mouth." It is an ulcerative or pseudo-membranous gingivitis, when confined to the gums, or stomatitis when the mucous membrane of the mouth is involved or tonsilitis or pharyngitis; in the last two locations the condition is commonly referred to as Vincent's Angina.

INFECTIOUS JAUNDICE (SPIROCHETAL JAUNDICE)

This disease, long known as Weil's Disease, was the cause of illness in 78 men, of whom five died. Numerically, therefore, it is quite unimportant, but because of its interesting epidemiology it deserves a few words. It is caused by the *Spirocheta ictero-hemorrhagica*, a common parasite of rats which was first described by Inada and Ido in Japan in 1915. The infection is characterized by irregular fever, well marked jaundice which usually appears about the fourth day of the disease, a tendency to hemorrhages from the mucous surfaces and into the tissues and hemorrhagic herpes or fever sores.

The disease occurred in small epidemics at various times and places in the armies of our Allies, the British, French and Italian, and the few cases occurring among our troops may have had some connection with these. The Japanese noted that the epidemics were limited to small groups, such as a family or a small group of soldiers in barracks; in mines, for example, it would be limited to the workers in a certain part of the mine.

The spirochete is exceedingly small and delicate, and about

the same size as the spirochete of syphilis, from which, however, it is easily distinguished by the beaded appearance of the body and the hooked ends. In suitable preparations it is seen to be actively motile. The motion is both that of rotation, undulation and progression. It has been cultivated in test tubes using the methods which Noguchi elaborated for the study of the spirochete of syphilis, and from these cultures the disease has been reproduced in animals, particularly in the guinea pig.

The diagnosis of the disease was more successfully made by demonstrating the presence of the spirochete. This was done by injecting a few cubic centimeters of blood from a patient, preferably the first four or five days of the disease, into the peritoneal cavity of a guinea pig, where it multiplies rapidly and its presence can be demonstrated. It is rarely present in the blood of the human being in sufficient numbers to permit of its demonstration without this enrichment in the guinea pig.

Later in the course of the disease, from the tenth to the fortieth day, the organism can be found in the urine by direct examination of centrifuged specimens. This is analogous to what occurs in the natural infection in the rat, as the organism has been found in the urine of apparently healthy rats, both house and field, in as high as 30 per cent. of those examined. This is true in Japan, on the French front, and also in certain places in America, where the rats have been examined.

It is possible to produce the disease in guinea pigs by giving them food contaminated with cultures of urine containing the spirochetes, and presumably the epidemiology of the disease in the human being is explainable in the same manner.

Weil's disease, which occurs sporadically in all countries, has been a mystery in the past, but thanks to the investigations of the Japanese, which have been fully confirmed during the World War, its epidemiology is now quite clear.

ANTHRAX

During 1918 there were 129 cases of anthrax reported among all troops of the army, giving an admission rate of 0.05 per

thousand of strength. Among these there were 23 deaths from the disease, making a rate of 0.01 per 1000. It was distinctly a war-time disease with us, since in times of peace the disease is practically non-existent in the service. It was early noted that the initial lesion of the disease, that is, the place where the infectious material gained entrance to the body, was on the shaving area of the face. Although many of the men billeted in stables and in buildings which had been used for animals, and in this country they were housed in buildings recently erected on ground used for animal shelters of one sort or another, it is improbable that these facts were of any importance in explaining the presence of the cause of the disease, since the lesion was so uniformly located on the shaving area of the face. This fact led to the critical examination of the articles used in shaving. Naturally the brush, being made of animal hair, came first under suspicion, and bacteriological examinations soon were successful in showing the presence of the spores of anthrax on the hair. Uniform reports came from all parts of the country and left little doubt but that the troops were being furnished by the Quartermaster with infected brushes. On the recommendation of the Surgeon General, the issue of the brushes in stock in all depots was suspended until they could be examined and disinfected. In the meantime, the United States Public Health Service was informed of the unusual prevalence of the disease, and was requested to institute an inspection service of the factories furnishing shaving brushes to the army, and to make recommendations regarding those whose output it was safe to purchase. The Public Health Service reported that previous to the war most of the cheaper grades of shaving brushes were produced in Germany, and that the German manufacturers were accustomed to using hair from Siberia, Manchuria and China, and knew that it needed radical disinfection. In this country, when the customary source of supply was cut off, brush factories of every sort, including those which had never before produced anything but paint brushes, began the manufacture of shaving brushes, without any idea

of the possible danger which might arise from using the imperfect methods which had sufficed for other classes of brushes. Hair of several kinds of animals was used, but all varieties, except horse hair, had to be boiled to straighten the bristle, and this boiling sterilized automatically all hair except the horse hair, and that alone was found capable of carrying infection. The factory inspection soon led to the use of correct methods and the new brushes purchased were safe. Since a large number had been produced and sold to the army and to civilians, a few cases continued to appear, but in decreasing numbers.

A review of the experience of the French and British showed that they had gone through an exactly similar experience and had our own manufacturers and authorities been closely in touch with foreign conditions we might have been spared the 129 cases and 25 deaths from this preventable disease.

GASEOUS GANGRENE

At the beginning of the war there was much confusion regarding the nature of this affection. One group of workers who had isolated the *Vibrio septique* from cases believed that to be the cause of the disease; another group, on finding the bacillus of Welch considered that organism responsible. Other workers from time to time isolated still other organisms. The entire subject was investigated thoroughly during the war by bacteriologists of the Allied nations, and at the present time they have practically agreed that there are eight different anaerobic bacteria which are capable of producing gaseous gangrene in both man and animals, and that they may be arranged in their order of importance as follows: (1) *B. welchi* (gas bacillus, *B. ærogenes capsulatus*, *B. perfringens*, *B. phlegmonis emphysematosæ*.) (2) *Vibrio septique* (*B. of malignant œdema*, *B. chauvei*, *B. symptomatic anthrax*, von Hübner III, *B. septicus*.) (3) *B. œdematians* (*B. gasoedem*, *B. bellonensis*, *B. novyii*.) (4) *B. fallax*. (5) *B. histolyticus*. (6) *B. sporogenes* (*B. enteritidis sporogenes*, *B. faulnis erberger*.) (7) *B. ærofetidis*. (8) *Streptococcus anerobius*.

In addition there are a fairly large number of other organisms which have been isolated from wounds of human beings showing gas gangrene, but which have not the power of producing the disease in animals.

Jablons reports that the following organisms are capable of producing a toxin and of progressive tissue necrosis and irreparable damage to the central nervous system: *B. welchi*, *Vibrona septique*, *B. œdematiens*, *B. fallax*, *B. histolyticus*, and *B. sporogenes*. Against all but *fallax* and *sporogenes* it has been possible to produce anti-toxic sera for the treatment of the disease.

Most of these organisms have been isolated from the soil, and as the troops in the trenches had their clothing constantly coated with mud or dust, it is easy to see how soil organisms would be carried into the wounds on fragments of clothing. They are commoner in soil which is polluted with excrement or heavily manured. As the soil of Flanders and most of the western front has been under intensive cultivation for centuries, all the conditions favorable for the development of gas gangrene were present.

The bacilli exert their damaging action very largely in the muscles; the fibres swell and quickly undergo necrosis with the development of bubbles of gas between the fibres. The quantity of gas is sometimes large enough to be felt as a cracking sensation as the hand is passed over the skin.

The treatment of gas gangrene is **primarily** surgical and consists of complete extirpation of the necrotic and infected wound down to healthy tissue. This radical treatment is usually referred to as debridement. In addition anti-gas gangrene serum is used, both as a prophylactic measure and for treatment of recognized cases.

Anti-gas gangrene serum. Bull, at the Rockefeller Institute, was successful in preparing an anti-toxin against the *B. welchi*, one of the most important of the gas gangrene organisms. He made use of an observation of Flexner's, that the bacillus of Welch was capable of producing lesions in pigeons quite com-

parable to those found in man. He soon learned that he could obtain a toxin from his broth cultures which produced a necrosis of muscle when injected into the pigeons, and that he could produce an anti-toxin by appropriate methods of immunization of larger animals with the toxin, and that this new found anti-toxin would neutralize the toxin both in test tube and in the body of the pigeon. The hope that was raised by this discovery that a cure for gas gangrene had been found was short lived, for it soon became evident that the bacillus of Welch was only one of many organisms capable of producing the disease, and that further anti-toxins must be prepared before much could be done. At the close of the war it had become possible to produce several other anti-toxins by using the same methods which had been elaborated by Bull, and the commercial manufacturers were ready to furnish a polyvalent anti-gas gangrene serum. The plans called for a single serum, made either from one horse, or by mixing the sera from several horses, which would contain anti-toxin for the tetanus bacillus, and the three principal gas producing anærobes. Anti-toxic serum against tetanus and *B. welchi* had already been manufactured in considerable quantity and was available for use during the offensive in the Argonne. Fortunately the Armistice intervened and no further research, because of war wounds, was necessary.

Although gas gangrene is present from time to time in civil practice, particularly in wounds due to industrial accidents, it has never been a common condition. In the past, unless complete surgical treatment was given early, the cases were quite hopeless. The experiences of the war have made it possible, therefore, to make provision for these sporadic cases, which, in total numbers, are quite considerable, although a single physician rarely sees many of them.

PNEUMONIA

The history of the diseases of the lung is as old as anything in human medicine, and yet much less progress has been made

in their study during recent years than in the diseases of the digestive tract, or in the tropical diseases or in several other categories of diseases. The reason for this is not perfectly plain, but it is perhaps because all these are diseases of human beings alone, having nothing in common with the diseases of animals or with those carried by insects or other hosts, and for this reason are not easily made the subject of experimental research on laboratory animals. In addition, the respiratory diseases are the most common of all human ailments, and most of them are so trivial that they have not received the study and attention that have been given to more fatal maladies. Very few of us give much consideration to a common cold and yet in the mystery of the common cold may lie the secret of many of the acute infections of the respiratory system.

At the beginning of the war there was every reason for expecting a considerable number of cases and deaths from pneumonias, since that had been the experience of the Civil War, and in civil life the percentage of deaths due to lobar pneumonia has been relatively increasing during recent decades as the more easily preventable diseases decreased. An orderly understanding of acute lobar pneumonia had also been arrived at through the work of Rufus Cole, Avary, Dochez, Chickering, and others at the Rockefeller Hospital, New York. The work began some years ago, about 1913, in fact, but the subject was complicated and difficult and progress, although steady, was slow. In the end, however, these investigators showed that the organisms which cause lobar pneumonia may be grouped into four classes, which they have designated as types one, two, three and four. The first three of the types are fixed and are readily identified by agglutination and precipitin tests and by some other biological and cultural tests. The fourth type, however, is made up of the irregular organisms which do not fall into any one of the first three types. The fixed types are clear cut homogeneous groups made up of similar individuals, while the fourth type consists of a large number of irregular organisms which bear no relation to the other groups,

nor to one another in their own group. In fact, they resemble in this the organisms found in the normal, healthy human mouth. From a study of these clearly defined types it has been possible to prepare a serum which is curative when given sufficiently early in the disease, for the lobar pneumonia caused by organisms of type one. Similar curative sera have not yet been prepared for the other types. In a study of 454 cases of pneumonia at the Rockefeller Hospital, it was learned that about one-third of all cases are caused by type one, a second third by type two, about 13 per cent. of type three and the remainder, 20 per cent., by type four organisms. We have then, a specific treatment for about one-third of all cases of lobar pneumonia. The mortality of this type of the disease is normally about twenty-five per cent., but under treatment with serum in suitable surroundings the mortality may be reduced to ten per cent. This treatment was rapidly gaining ground, but, like other new things in medicine, had not yet become generally accepted through the country, and very few hospitals or physicians were prepared to make the bacteriological diagnosis or to apply the indicated treatment. To provide for this condition, classes of otherwise well-trained bacteriologists and clinicians were organized in our principal hospitals and laboratories, and systematic courses of instruction were given. Several hundreds of the younger medical officers passed through the Army Auxiliary Laboratory No. One at the Rockefeller Institute and the Yale Army Laboratory School at New Haven. When these men were distributed to our large base hospitals they in turn organized schools for special instruction of the staffs in the diagnosis and treatment of the diseases of the lungs, including tuberculosis, of empyema, and of cerebro-spinal meningitis, and of the other commoner epidemic diseases. Nothing in the medical history was more inspiring than the spirit and energy with which our men undertook the study and systematic investigation of the important problems which confronted them. The greatest of all the new fields was in the respiratory diseases which were unusually common, quite severe

and the cause of tremendous loss of life, and of training time of those who recovered. Even had the appalling epidemic of influenza not occurred it would still remain true that the respiratory diseases were the most important group with which we had to contend.

When the troops assembled in the Fall of 1917, men from the cities and from the country district were brought together in intimate association in our training camps, and the carriers of disease germs quite early infected those who were susceptible, with first one and then another of the acute infectious diseases; those which we are ordinarily in the habit of calling the diseases of childhood. Of these measles was the first to appear, and it passed through first one camp and then another until practically all the susceptible material was exhausted. It seemed quite impossible to prevent its spread when introduced into an organization, although a great deal was accomplished in modifying its severity and in preventing its complications. During 1917, 32 per cent. of all deaths were due to this disease, and it caused a mortality of 1.7 per thousand of the strength of the army. In 1918 there were fewer cases. In the American Expeditionary Forces the disease was constantly present, but it never assumed the proportions of an epidemic as it did in the United States, for the simple reason that the troops sent overseas were relatively seasoned, or salted as the British say, when speaking of troops which had already acquired an immunity to the diseases of childhood. For the two years of the war there were 98,606 cases, and 2455 deaths. In spite of these large figures, we know that the disease was less serious as a military difficulty than during the Civil War. Had the same rates prevailed as in 1861 and 62 there would have been 184,918 cases and 6649 deaths.

Measles is always a serious disease and is the cause of a large mortality among children every year, especially in our large cities, and it deserves more study and research than has been given it. We made several attempts to unravel the riddle of the disease, but without success, and we are to-day in no

better position to prevent its spread than before the war. The single improvement, if such it can be called, is in our present appreciation of its importance, and of the necessity for further research, as to its cause, in order that we may have knowledge to prevent or at least to control its spread, most probably by the discovery of a suitable vaccine.

Simple, uncomplicated measles is probably a mild and almost harmless infection, but unfortunately complications are common and severe, the most important being pneumonia. In this war the pneumonia was studied as have been the ordinary or lobar pneumonias, and it was early learned that the inflammation of the lung was of quite a different character; that is, was ordinarily caused by the type four pneumococci, or even more frequently by the hæmolytic streptococcus. The last named organism is the cause of some forms of septicemia, of erysipelas, of puerperal fever, and of many wound infections, all these conditions being serious and often fatal. The pneumonias caused by this organism were frequently complicated with empyema, and were very fatal. Many studies of the complications of measles were made in all our larger camps where the disease prevailed, by the foremost investigators of the country, and the importance of the disease, from a military standpoint was realized as never before, and we may reasonably expect some solution of the riddle of the disease, provided the science of bacteriology and of immunology is sufficiently far advanced to furnish us with a workable technique for its study. At the present time the chief stumbling block is the practical impossibility of producing the disease in animals. This limits the experimental work which can be done quite sharply.

INFLUENZA AND ITS COMPLICATIONS

Pestilences of one kind or another are popularly supposed to follow upon the heels of war, and history does indeed show many such associations, as, when, for example, smallpox spread through France during the Franco-Prussian War, and through

Germany soon after peace was signed. In our own Spanish War we were assailed with a plague of typhoid fever, which left its imprint upon our civil death rate for years after 1898. A recurrence of either of these diseases had been rendered impossible by the general practice of vaccination against them. Indeed it would not be an exaggeration to affirm that the war could not have lasted as long as it did, had it not been for the success of the vaccination program in all the armies involved, including those of the Central Powers. No one ventured to prophesy that influenza would be the scourge of this war, although it would not have been illogical. It is a very old and well known although little understood disease. Since the fifteenth century we have had periodical pandemic waves of the disease, extending to the remotest points of the world. The interval between epidemics has usually been twenty or thirty years. The last preceding world epidemic was in 1900. It is characteristic of the disease that it travels as fast as the modes of human transportation permit, remains at any one place for little more than a month and then passes on to new regions until it has reached the most remote corners of the civilized world. The long interval between epidemics makes it inevitable that each new epidemic must be studied by a new group of investigators. It takes the men an appreciable time to learn the difficult technique which is necessary, and before many have acquired proficiency the disease, and with it the opportunity for its investigation, has passed. Pfeiffer did not discover the influenza bacillus until 1902, two years after the crest of the epidemic had passed, and for this reason many skeptics doubted if he was dealing with the true epidemic disease.

In this visitation, the disease was called the Spanish Influenza, an old name, since several times before the disease has first been recognized in that country. Almost as often it has been called the Italian influenza. The epidemic of 1900 came out of Russia and was commonly called La Grippe.

There is really no reason to doubt that it has always been the

same disease, although the laboratory proof is still lacking, because the clinical course of an attack of the disease is so characteristic.

What is the history of influenza in inter-epidemic years? In the absence of complete proof it is impossible to be sure about it, yet the most commonly accepted belief is that the disease is always with us, as the ordinary influenza, a form of common cold, but that only under exceptional circumstances does it become virulent and cause any appreciable mortality. Dr. Welch showed years ago that the influenza bacillus could be recovered frequently at autopsy from the cavities in tuberculous lungs. Others have shown its presence in chronic diseases of the sinuses accessory to the nose and throat. In other words, the causative organism is regularly present, but of low virulence, and it does not prove sufficiently fatal to cause an appreciable influence on the annual mortality curves. Why some diseases, such as infantile paralysis and influenza, should suddenly become extremely virulent and produce wide-spread epidemics we do not now know. During the war it is probable that it obeyed the same law as measles, and spread among our soldiers because they were young, many of them from the country districts, and, therefore, not immune to the infection. As the conditions were ideal for the rapid passage of the virus from man to man, it is concluded that there was a steady increase in virulence, until the virus was capable of causing a very severe and fatal illness.

During the last four months of 1917, when the camps were filled with recruits, there were reported 40,512 cases of influenza, yet it was not noted as a severe disease, and it was not apparently followed by pneumonia to any serious extent. In the Winter and Spring of 1918, particularly in January, March and April, many cases of influenza were again reported, as well as many fatal cases of pneumonia. It was not until the Fall, however, during September and October, that it was recognized that the fatal epidemic form of influenza was present, and that pneumonia was reported as a frequent and fatal complication.

The particular strain of the virus responsible for this seems to have been brought to Boston from Brest, the first week in September. From Boston and Camp Devens the disease spread as rapidly as human beings travel to all parts of the United States. The further history of this virus we do not know, and we may indeed never be able to trace it. We know the disease in a mild form was present in our camps from the beginning, and that our troops presumably carried it with them wherever they went. We know that the French had a similar experience with their own colonial troops, and it is probable that the experience of all the warring nations was the same. From a military point of view one is justified in saying that travel was free and uninterrupted from the ends of the world to the seat of the war in France. Troops from all the world were poured in daily and a returning stream of wounded, sick and broken down men, returned to the home countries and carried with them the germs of any respiratory infection to which they had been exposed. The virulent virus, therefore, wherever it first arose was soon carried across the battle lines, to friend and foe, to the lines of communication in the rear of the battle areas, and finally by ships, from port to port.

It stands as one of the most fatal pestilences of history. For 1918 there were reported 688,869 cases in the American Army. This gives a rate of 273 cases per thousand men. The number of deaths charged directly to influenza was 23,007, giving a rate per thousand of population of 9.14. In addition to this number of deaths, there were 431 charged to bronchitis, 6814 to broncho-pneumonia, 8407 to lobar pneumonia, and 405 to pneumonia unclassified, 262 to pleurisy, 330 to various respiratory diseases, a great many of which should, no doubt, have been charged to influenza. If these deaths are added together it would give a total of 39,701 out of a strength of 2,518,499 during the year, a rate of approximately 15.75 per 1000 of population. The total deaths for the army for the year from disease amounted to 47,384. Approximately 82 per cent. of all deaths were, therefore, caused by diseases of the respiratory

tract. If we deduct this respiratory rate of 15.75 from the total rate for disease, it would leave the exceedingly low rate of 3.07 for all others.

We may conclude, therefore, with this evidence, that it is possible to prevent deaths, under conditions of mobilization and warfare, from all diseases except the respiratory; that so far as such diseases are concerned we have advanced but little, and that the field for future investigation and research for all concerned in public health and medicine lies in the diseases of the respiratory tract.

Some progress has already been made; secondary pneumonias from the hæmolytic streptococcus are now recognized and methods for their control are now available. There are those who believe that epidemic influenza, and the influenza of inter-epidemic years, is caused by the bacillus of influenza, but even so, there does not seem to be at the moment of writing any method of preventing an epidemic which has once started. This is, perhaps, the greatest of the public health problems at present awaiting solution.

XVIII

ADVANCES IN SURGERY DURING THE WAR

JOHN W. HANNER

WHILE there has been nothing startling or revolutionary in the surgical art as a result of the recent great war, substantial and valuable gains in the surgical field have marked the progress of surgeons of all nationalities through the multiplicity of conditions met with, and valuable knowledge for future use has been stored up in the literature.

Perhaps the outstanding and most spectacular achievement, one that shortened the period of disability greatly and resulted in the early return of the soldier to the fighting line, as well as prevented large, mutilating and often disabling scars and contractures, was the early closure of wounds, after thorough excision and cleansing of the lacerated, devitalized tissue found in and around the track of the projectile, a procedure called by the French "*débridement*."

This excision of tissue and immediate closure of a wound is successful only when it can be done within a short period after the receipt of the wound, usually given as eight to twelve hours. As a rule, when a longer time has intervened, infection of the wound has already gained such headway and has become so widespread, since the organisms have had time to multiply and penetrate into the surrounding tissue, that it is unsafe to close the wound immediately. In such cases, it has been found safer to delay the suture of the wound for two or three days, when in favorable cases it can be closed without fear of future infection; or to employ antiseptics to combat and limit the infection; or to use simple drainage, as was formerly done, until the

infection is controlled, after which a freshening of the edges of the wound can be done and a secondary closure, perhaps after two or three weeks, be successfully performed. The success of early closure of wounds depends, then, on getting the wounded man to a surgical formation as soon after being wounded as possible; for the earlier a wound has surgical treatment, the greater the chance of success in immediate closure, when the wound, after thorough excision of the injured tissues, behaves as does a clean wound made by a surgeon in ordinary civil operating, healing taking place without any complicating suppuration. This necessity of early surgical treatment was met by improved methods of evacuating the wounded from the battlefield and by moving the surgical hospitals and operating teams as far forward as safety of the wounded permitted, in order to shorten the haul to the place where surgical aid was available. Constant improvement along these lines resulted in the reception of the wounded and operation upon them within an average time, in the majority of cases, of six to eight hours after the receipt of the wound.

It had been hoped that the incidence of infection of war wounds would be less than had occurred in former wars, due to the use of the so-called "humane," small caliber, high velocity bullet of the modern military rifle. But, as a matter of fact, such did not prove the case since, especially as the war progressed, the number of those wounded by the small bullet was a small percentage only. The great majority in the later stages of the war showed wounds from shell fragments of the high explosive shell, which was used more and more as the number of field guns and long range cannon increased, and such wounds were invariably potentially infected. Wounds from shell fragments are torn, jagged and lacerated, and the mass of macerated, devitalized tissue surrounding the track of the projectile is increased. Hence débridement or total excision of this injured tissue is rendered more difficult, and requires much patience and painstaking care to insure that all of the bruised and infected tissue is entirely removed, for this is essential to

the success of immediate closure. Added to this was the fact that the soil of the western battle front, in Belgium and Northern France, had for many generations been intensively cultivated, and manure and human dejecta had been used for fertilization. As a consequence the soil fought over was richly impregnated with bacteria, especially of the fecal variety, both spore bearing and non-spore bearing. The spore bearing organisms are very tenacious of life and resistant to destruction. Among these fecal organisms the most important and virulent met with in the war were the *bacillus tetani*, which causes tetanus or "lock-jaw," and the *bacillus ærogenes capsulatus* (Welch) or *perfringens*, which causes gaseous gangrene. There are other varieties mixed with these and usually found associated with them in wounds; but these are the ones which, especially in the earlier stages of the war, caused the greatest mortality in the wounded. The clothing of the soldiers was necessarily more or less fouled with the germ-laden earth; often their skins were dirty, too, for a dainty toilet and ideal cleanliness are not often possible under field conditions; so that when a wound was inflicted these virulent organisms, together with the ordinary pus-producing bacteria, were carried into the depth of the wound either on the projectile itself, or on shreds of clothing or skin which are usually carried into the wound by the projectile, and there they found a favorable home in which to multiply and elaborate their toxins. The "lock-jaw" and "gas gangrene" bacilli are anærobic, that is, they flourish only when they are protected from the action of oxygen or air; so that deep wounds and those which exhibit pockets or side tracks are the ones which are best suited to the needs of these organisms. Naturally, then, the rational treatment of such wounds and the one practiced with success if the patient was seen sufficiently early was either excision of the entire wound, or if such was not possible, the thorough and wide opening up of the wound so that there were no pockets or crevices left which prevented the access of air to them. Due to the high incidence and the fatal effect of tetanus or

"lock-jaw" when once the system has absorbed the toxins of the tetanus bacillus, it early became the practice, which was continued throughout the war, to give a prophylactic or preventive injection of tetanus anti-toxin at the first sanitary formation to which the wounded man was taken, usually the battalion aid or collecting station. This injection of anti-toxic serum was made mandatory and each wounded man was so protected, however apparently trifling the wound; as a consequence the occurrence of "lock-jaw" became a rarity instead of a common complication.

Though the incidence of gaseous gangrene was greatly lessened by early surgical intervention, cases which were seen late frequently already showed the infection as well established, and then the problem became one of control instead of prevention. Various measures were proposed for combating and limiting its spread, the most popular of which were the injections of oxygen or peroxide of hydrogen, which gives off free oxygen, in the tissues beyond the infected area, in the endeavor to prevent an extension of the process. The value of these measures is very doubtful, since tissues distended with the oxygen or peroxide are rendered tense and their blood supply lessened by pressure; in other words, tissues which are uninjured are really damaged and rendered less able to combat by their natural processes the invasion of the organisms; hence these means were not widely employed though some surgeons claimed that it was really beneficial and the gangrenous process was limited by use of them. Unfortunately, often, when massive gangrene had already supervened, temporizing measures were too risky, and amputation had to be done as a life-saving measure. In less severe cases, in which a muscle or group of muscles only was involved, excision of the infected muscle or group, as the case might be, resulted in the saving of both life and limb.

The importance of immobilizing for transport the wounded part, whether it involves bone or is of the soft parts only, in aiding to prevent or limit infection, is more fully appreciated

now as a result of war experience than it ever has been before.

When infection of a wound is evidently unavoidable or is already frankly present when the patient reaches surgical aid, either through inability thoroughly to excise the wound, if seen early, or due to the general condition of the patient which prevents a radical primary operation, or through the impossibility of early evacuation to a surgical hospital, the problem of early control of the infection, cutting short its course, so that the wound may be sterilized and rendered capable of secondary closure without the long wait for healing from the bottom out by granulation, is the effort to which the surgeon bends his knowledge and energy. In the years of peace, surgeons had striven steadily with success to render surgical operations aseptic or free from infection, and the use and elaboration of antiseptic agents, employed to destroy bacteria and control infection, had claimed but little of their thought and attention. Faced with the treatment of many and virulently infected wounds, interest in antiseptics was revived and out of experiments with many substances and many methods of application were evolved successful means of combating infection. Holding first place, probably, in efficiency of controlling infection is the Carrel method of wound sterilization by use of Dakin's solution. Dakin's fluid is a solution of sodium hypochlorite of a given strength, 0.45-0.5 per cent. of the hypochlorite. If stronger than this it is too irritating; if weaker, it has but small antiseptic power. If employed haphazard, in any sort of fashion, it has no more value than any fluid employed for irrigation or mechanical cleansing. Carrel worked out a method which utilizes its full antiseptic value. He found that by the use of many small, soft rubber tubes (4mm. inside diameter) with small perforations in the tubes towards their ends, so that the fluid might be evenly distributed in the wound, this antiseptic fluid could be brought into contact with all the wound surface. By trial the frequency of the use of the fluid in the wound was determined to be at two-hour intervals for the best results. To get results the technic as elaborated after

long study and experimentation by Carrel should be carefully and rigidly followed. Dakin's fluid is antiseptic for only a brief period, and to act must be brought into actual contact with the infected tissues, which is best accomplished by rigid adherence to the technic as laid down by Carrel. As remarked before, failure follows haphazard, hit-or-miss methods. Many surgeons have failed to get results with Dakin's solution, and have pronounced it valueless, but investigation in such cases usually shows that they have applied it in a way of their own and have disregarded the teachings of Carrel as to its proper methods of use. The surgeons who have followed the method rigidly as recommended are usually successful and become enthusiastic advocates of this means of controlling infection. Remarkable results in the prompt control and quick sterilization of badly infected wounds have been reported in great numbers, permanent secondary closures then becoming possible and usually proving successful.

Rutherford Morison, an English surgeon, has advocated the use of a paste composed of Bismuth subnitrate, or carbonate, iodoform and enough liquid paraffin to make a paste — this paste being commonly called "Bipp" from the initial letters of its components. The English have used it with success and Morison claims that by a few dressings with it, many wounds can be sterilized at once, while in the remainder the spread of infection can be checked and remedied.

For the treatment of infected wounds Sir Almroth Wright also introduced his hypertonic salt solution. Normal salt solution, 0.9 per cent. of ordinary table salt in sterile water, has long been used as a cleansing fluid, with perhaps mild antiseptic properties. Wright's Hypertonic Solution is a solution of salt in water in the strength of 5 per cent., over five times the strength of the normal saline. A fresh wound has a coating of lymph from the tissues of the body formed on the wound surface in a comparatively brief space of time. This seals the surface of the wound, and bacteria multiply unhindered beneath this protective coating. The use of five per cent. salt solution

prevents the formation of this film of lymph and invites the flow of lymph from the tissues, causing what Wright terms "lymph lavage." This lymph is one of the protective fluids of the body, and the constant outgoing stream of it through the infected tissues serves to carry away with it the bacteria which are growing on the surface and to prevent their deeper penetration.

The above have been the most successful methods of treating infections which have already become established and of preventing serious infection in wounds in which surgical cleanliness could not be obtained.

Brief mention should be made of the treatment of shock. No specific treatment has been discovered; it is still symptomatic. Cannon did valuable work in this field. While nothing new in treatment has been added, methods of treatment were rendered available and efficient, which had not been so formerly in the field with armies. So-called "shock teams" were organized, consisting of personnel specially trained in the handling of shock cases, and these teams worked in the hospitals in the advance zone. The evacuation and mobile surgical hospitals had wards set aside for the treatment of these cases, and the personnel to carry out the treatment. Field hospitals and triages had litters so arranged as to warm up quickly and to keep warm any patients received in a state of shock, and ambulances heated from the exhaust were used to transport them. The warming and keeping warm of a patient in shock is still a great necessity. Acidosis, an acid condition of the blood, which is normally alkaline, is present in shock, and Cannon combats this with success by giving sodium bicarbonate by the mouth, and a 4 per cent. solution of it intravenously, introduced very slowly, about an ounce a minute. The menace of low blood pressure is met by position, prone, or head lowered, except in cranial and chest wounds, as little movement and handling as possible, and many advocate the use of 6-10 per cent. glucose and 5-7 per cent. gum arabic solutions in the veins, either alone, or with glucose added, and perhaps a small per-

centage of adrenalin; but the stimulant effect of the latter is very fugitive. Blood pressure readings are taken at frequent intervals, and treatment regulated thereby.

Porter advocates the treatment of shock by means of carbon dioxide, which is introduced into a box in which the patient's head is enclosed, enough gas being used to double the number of respirations. By employing this carbon dioxide treatment, in addition to the posture, the warming, and the intravenous injections, Porter claims to have 80 per cent. of successes, even in the cases of profound shock.

Another important advance in war surgery was the early splinting of the wounded, as far forward as possible. Some splints were applied even on the field, many at the battalion aid stations close behind the firing line, while it was the endeavor to have every man splinted before being evacuated from the "triage" or sorting station of the wounded to formations farther back. This splinting applied not only to fractures and joint wounds, but to extensive wounds of the soft parts as well. It resulted in greatly lessening shock, rendering the wounded more comfortable and thus keeping up their morale, preventing further injury from movement of the wounded part during transportation and so delivering the patient in better condition for immediate or early operation. This was accomplished by standardizing the splints throughout the army, making them simple, easy and quick of application, training the sanitary personnel in their proper application and adjustment, and having a sufficient supply for their needs at all times with the combat units. Better final results in the treatment of wounded resulted from this early and far-forward splinting.

A very distinct and one of the most far-reaching and beneficial results of the war was the realization of the surgeon that his duty had not been fully accomplished in getting a wound to heal or a fracture to unite. Too often in the past the general surgeon was satisfied with just this, and as a consequence not enough attention was paid to the future function of the wounded member. Due to the teaching and indefatigable effort

of the Orthopædists both of this country and of England, the general surgeon's view was broadened and his attention was directed to preserving of function even at the expense of quick healing, though in most instances the one did not interfere with the other. As Sir Robert Jones, the eminent English Orthopædist, expresses it: "The orthopædic mind thinks in terms of function." During the war *preventive orthopædics* was practiced, as distinguished from *corrective orthopædics*. The latter is and has long been more especially in the province of the Orthopædic Surgeon. The former, however, should lie in the province of every surgeon who has to deal with war wounds. The world war has taught the general surgeon a lesson in *preventive orthopædics* which will never be forgotten, and the benefits of this lesson will be carried back with him into civil life. Many deformities and crippling as to function will be prevented which have hitherto occurred more or less as a matter of course, requiring secondary operations or *corrective orthopædics* to gain what might have been prevented in the first place. This advance we owe to orthopædic surgeons and their insistent teaching. Results obtained augur well for the future. But to obtain them it was early learned that a consistent line of treatment must be followed, not haphazard methods. This was accomplished by having uniformity of treatment from front to rear formations, so that the wounded, even though necessity compelled him to pass through the hands of different surgeons, was assured of the continuation of the treatment instituted in his case by the first surgeon who attended him, and by the best methods experience had shown as giving the best results in the individual cases.

Another advance in surgery or in being better able to do good surgery was the aid and increased use of the roentgenologist, who, during the war, became a more important factor than he had ever been. He operated far forward; practically all cases passed through his hands before operation and the information he was able to furnish was invaluable in indicating the proper operative procedure. Through advances in the roentgenologic

art foreign bodies were more accurately located than they had ever been before. Several very simple and accurate methods of locating the foreign body within a fraction of an inch, rapidly applied without long mathematical calculations, were perfected. Too, the roentgenologist became an anatomist as well, and not only could he give the depth from the skin surface at which a foreign body lay, but he could locate it further by its relations to well known anatomical landmarks. By aid of the roentgenologist, the surgeon could also cut directly down upon and remove under X-Ray vision, by means of the fluoroscope, a foreign body which might be small, difficult to find or difficult of access, without such direct X-Ray vision. Thus the roentgenologist has become in operating a most valued and important assistant of the operating surgeon.

As a product of the war there was also perfected a portable bedside X-Ray unit, capable of taking excellent roentgenographs and of being used with the fluoroscopic screen. This operates from the ordinary incandescent lamp socket or wall plug. No longer is it necessary, during convalescence and the progress of union, to move a patient with a fractured bone to determine the position of the fragments. This can now be done at the bedside without moving or disturbing the patient in the least, with the consequent risk of displacing the fragments which such moving entails. X-Rays will be taken more frequently during the mending process. Any displacement will be corrected early, fewer cases of vicious union or non-union will occur, and better results in fracture work will result.

While there has been, perhaps, no distinct advance in the treatment of wounds of the cranium and abdomen when operated, lives have been saved by early operation of these cases. Formerly, due chiefly to the too long interval between the time the patient was wounded and the time surgical aid was available, the teaching was that expectant treatment — non-operative, that is, merely meeting symptoms as they arose — resulted in saving more lives than operation did. This has now been reversed. Improvement in evacuation methods, and the moving

of surgical hospitals with competent and trained surgical personnel to operate these special cases far forward, has resulted in getting the wounded to surgical aid quickly, within a few hours after the receipt of the wound. Under such conditions operation on these cases is indicated; the sooner the operation is done the better the chance of success. So that now, as has long obtained in civil surgery, in war surgery, too, these cases are no longer treated expectantly, but are operated when seen early and the mortality in such cases has thereby been very materially reduced.

In chest wounds a distinct advance has been made in one direction. It has been discovered that opening the chest cavity and thereby allowing air to get in is no longer to be feared for its dire results as formerly. Such fear of air in the chest cavity (pneumothorax) has been found to be largely mythical. Now bruised, devitalized and potentially infected lung tissue is excised, hemorrhage in the chest is stopped, and lung tissue is sutured as is the soft tissue anywhere in the body. In other words, wounds of the lung are débrided or excised and treated as are other wounds of the soft tissues. In the old cases of pus in the pleura, pyothorax or empyema, in which the pleura is greatly thickened or leathery and no longer elastic, imprisoning the lung and preventing it from expanding, the earlier method was to excise the chest wall and allow it to collapse, thus filling the cavity in the pleura so that it will no longer discharge pus. According to present methods, such amounts of the ribs as may be necessary to permit a free access to the affected part of the pleura are resected, care being exercised that the periosteum or membranous covering of the ribs is preserved, this thickened pleura is then excised, peeled off of the chest wall and of the lung, permitting the lung to expand and function again. The soft parts are closed, the membranous covering of the portions of the ribs taken out is left in place, the ribs soon grow back, and the old deformities of a collapsed chest wall and drooping shoulder are no longer evident.

Mention should be made of the great value of the X-Ray as a diagnostic agent in empyema cases, especially if stereoscopic use of plates is employed; the extent of the empyema or delimitation of the cavity to be dealt with is plainly brought out.

A decided advance has been made in the management of wounds of joints. As a result of experience in joint wounds during the world war it has been proved indubitably that the lining membranes of the joints (synovial sacs) are quite resistant to infection, taking rank almost with the lining membrane of the abdomen and its contained organs in this respect. Early immobilization of joints which have been wounded, in case they are already infected, will usually prevent the spread of infection; and the resisting power of the synovial membrane lining the joint will confine the infection to a limited area, so that the whole joint will not become involved, and it is necessary then to drain only the infected portion. Since it has been ascertained in these cases that the joint membrane has the power to control and overcome mild infections, joints are now fearlessly closed primarily, after excision of the torn and possibly infected wounded area and the cleansing of the joint of extravasated blood and perhaps bits of foreign bodies and detached bone fragments, where former teaching would have led to prolonged drainage with a resultant stiff joint or one with limited motion. It has also been discovered, contra to former teaching, that drainage tubes introduced into or through a joint prolong the suppurative process and retard recovery instead of hastening it, so that now when drainage has to be instituted, the tubes are carried only down to the joint but never project into it. These facts, together with immediate immobilization of joint wounds, followed early in convalescence, usually certainly not later than ten days to two weeks, by passive and active or voluntary movement of the joint, so as to avoid stiffness, or a rigid (ankylosed) joint, have resulted in retaining function which, under former methods of treatment, would have been lost entirely or severely limited. By having the

patient himself gradually increase the range of motion of the joint, entire restoration of function is obtained in a majority of cases; the muscles do not atrophy and shrink and lose their power, as they do when they are long immobilized and not allowed exercise, and convalescence is thereby much shortened, not only redounding in benefit to the patient himself, but to the economic gain of the country at large.

A radical change in the treatment of infected joint wounds has been introduced and advocated especially by Willems, a Belgian surgeon. He uses no drainage tubes in suppurating joints, but at stated intervals the patient is required to move his joint, which movement expresses the contained pus through the incisions made into the joint for the escape of the pus. Remarkably good results have been obtained by Willems and others who have employed this method of treatment. They claim that better drainage is obtained than by the use of drainage tubes, the infection is more quickly controlled, the joint cleans up more rapidly, and it is a rare occurrence to have a stiff joint result when the treatment by movement is persistently and consistently employed. In this method of treatment movement of the joint is begun in twelve to twenty-four hours after the joint is opened by operation. Willems states that, contrary to what one would expect, after the first few times movement of the joint causes no great pain, since the pain on movement is due to inflammation and the acute inflammation quickly subsides, drainage by this means is so efficient.

What has been said of joints, as to early movement and exercise of the muscles of the wounded member, can also be said of fractures. The importance of frequent roentgenograms during convalescence has been mentioned; progress of union and the assurance that fragments remain in proper position are ascertained by them. No longer are fractures immobilized by rigidly immobilizing the entire injured limb with nearby joints rendered incapable of movement. By the suspension treatment of fractures, constant extension is obtained by a system of pulleys and weights, so that even though the joints are

moved and the muscles are exercised, the extension pull remains constant, the patient is no longer helpless and dependent upon nurses or orderlies even to shift his position in bed; he can move about in bed to a limited degree, of course, and is required to move and exercise the muscles and joints of the fractured extremity. This process hastens bony union in that it improves circulation, prevents stiffness of joints and atrophy of muscles from disuse, and thus again shortens the period of convalescence, allowing the use of the injured member much earlier than was formerly thought possible. Too, the early use of ambulatory splints for walking during convalescence hastens return to normal use and lessens the vicious "crutch habit."

Though nothing new has been added in the matter of bone grafts, bone grafting is now done with greater success probably than formerly. Instead of covering in defects of the skull with foreign material, such as metal plates, as heretofore has been the usual practice, it has been found that a thin shaving of bone with its covering membrane or periosteum transplanted bodily from a nearby portion of the uninjured skull, will unite with the bone around the defect, will grow and thus give a homogeneous bony covering for the area of lost bone.

When amputation has to be performed, greater attention is now directed to the effort of obtaining an end-bearing stump, that is, a stump which will take the weight of the body, when the leg or thigh has been amputated, on the end of the stump against the artificial limb, instead of the pressure of weight-bearing falling upon the sides of the stump. An end-bearing stump is altogether desirable and offers many advantages. Now, under the supervision of the surgeon, hardening and toughening of the end of the stump is begun as soon as healing permits, and by graduated steps of pressure and pounding and the early use of a temporary or provisional artificial leg, the stump is rendered fit for the wearing of the permanent limb much earlier than formerly. Also, more attention is paid to the "shrinking" of the stump, with the same end in view. All of this is done under the supervision of the surgeon and

no longer is a man dismissed and sent to a dealer in artificial limbs to be fitted; his final fitting is given before he is dismissed from hospital and the proper sort of device is chosen best to fit the individual case, with an eye chiefly to the man's occupation. Also, he is educated in the use of the new appliance before dismissal. The early use of the artificial leg lessens the period of crutch using and obviates the undesirable "crutch habit."

New knowledge has been acquired which assures greater success in dealing with lesions of the peripheral nerves. It has been ascertained that the fasciculi or smaller bundles of nerve fibers, which together make up the nerve trunk as a whole, have special functions of their own, and to obtain the best success in suturing a divided nerve these bundles of fibers should be joined to the corresponding bundles of the other end in suturing, so that the special tracts will be continuous. Hence the greatest care is now exercised to place the nerve in its correct anatomical continuity and to avoid any torsion or twisting of the nerve ends in joining them. Also, it seems to be definitely determined that surrounding the sutured segments of nerves with extraneous material, such as fascia, various membranes, gutta-percha tissue, segments of veins, which was done in the endeavor to prevent adhesions, is undesirable since it interferes with new-formed blood supply to the injured portion of the nerve and so retards regeneration. The best bed for a sutured or transplanted nerve is vascular muscle tissue, and there is a minimum of adhesions where the nerve can course between the inter-muscular planes. Success has not generally attended the transplantation of nerve segments; it is far better to join the severed segments of the divided nerve to each other when at all possible, and this is usually possible, for gaps of considerable extent can be bridged by proper position of the arm or leg in bringing the too short segments together without tension.

Great strides forward have been made in maxillo-facial surgery in obtaining both functional and cosmetic results. Surgeons and dental surgeons, working together to a common

end, have succeeded in correcting most frightful and repulsive disfigurements and deformities of the face and jaws into the lineaments of quite presentable human beings. Whole jaws and sections of the bony structure of jaws and face are built up prosthetically, contours are rounded out, scars excised, and tissue and skin from other suitable portions of the body are transplanted and grafted to fill in the soft tissues which have been burned or blown away. New eyelids, new eyebrows, new noses, new mouths and lips, new chins, new ears and cheeks are successfully made, restoring the contour of the face to as near a likeness to the original as can be obtained. This work requires infinite patience, optimism, and a steadfastness against discouragement, often many operations, but the results have been nothing less than marvelous in cases one would judge utterly hopeless of any possible benefit. Each case requires careful and individual study, and the procedure to be attempted should be fully worked out and determined, and accurate patterns of flaps, etc., made before operation is begun.

A weak solution of sodium citrate mixed with blood will prevent its clotting. Based upon this fact, a simple method of blood transfusion with simple apparatus has been perfected to replace at least a portion of the blood lost from hemorrhage. The technic is so simple, the apparatus required for its use so simple, that it can be done far forward and by surgeons of only ordinary ability, so that new blood can be supplied to one who needs it at a time when it will have the best effect, shortly after the original loss of the blood. Proctoclysis, or the slow introduction of normal saline solution into the rectum, to aid the system in the making of its own blood and to help combat shock, maintains its place of importance and value.

The recent war has resulted in extending the surgeon's interest to the field of reconstruction and reëducation, which in a way, properly falls under after-treatment of surgical conditions. The surgeon's advice and supervision in reëducating the maimed and crippled is naturally of high value, based upon his study of and knowledge of anatomy. He can best

direct the course of reëducation so that the maximum beneficial results can be obtained. The direction of his energy and knowledge to this end will redound largely to the happiness of the individual who can be transformed from a helpless burden to a more or less useful existence, as well as prove an enormous economic saving to the nation as a whole.

The knowledge gained in improved methods of surgical treatment during the world war will result in better results in the treatment of industrial accidents in peace time.

XIX

PREVENTIVE MEDICINE AND THE WAR¹

VICTOR C. VAUGHAN

NO educated man, civilian or military in his training and life, now questions the importance of keeping the soldier free from infection. That health is at all times a nation's greatest asset and disease its greatest liability has become a recognized truism. Never in the history of the world has preventive medicine had so great an opportunity to demonstrate its value in the service of mankind and that it has not failed in this demonstration all admit. From all parts of the earth, bearing every known infection, millions of men have been assembled and disease has at no time and in no way become a deciding factor in any military enterprise. The mobilization of raw untrained men, and their hurried transformation into effective soldiers, has always been accompanied by marked increase in morbidity and mortality. The assembly of young men in camps acts like a drag-net bringing to a central point all infections prevalent in the areas from which these men come. The wider the area, the larger the number of those brought together, the greater the susceptibility of the individuals constituting the assembly, the more closely they are crowded together and the more intimate their contact, the larger the number of bearers of infections, the more virulent the disease-causing organisms brought into the camps, the greater will be the morbidity and

¹ For the scientific details upon which this Chapter is founded see papers by Col. Victor C. Vaughan and Capt. Geo. T. Palmer in the "Journal of Lab. and Clinical Medicine," August, 1918, and July and August, 1919.

mortality from communicable diseases. Our Government assembled within less than two years nearly four million untrained, undisciplined men, most of whom were unacquainted with the details of personal hygiene and without experience in caring for themselves under conditions of army life. That the morbidity and mortality from communicable diseases among these should show an average above that in the civilian life from which they came was to be expected by one familiar with the science of epidemiology.

The purpose of this writing is to ascertain to what extent preventive measures succeeded in holding down the death rate from communicable diseases among our soldiers, especially in the camps in this country. In doing this it will be best to divide the period covered by our active military operations into three seasons: (1) From Sept. 29, 1917, to March 29, 1918. On the first of these dates the camps were fairly well developed and this period covers the winter months and our findings can be compared with the summer months with reference to the seasonal influence on the character and spread of infections. (2) From March 30, 1918, to August 31, 1918. Under usual conditions the month of September would have been included in this "Summer Season," but the appearance of the pandemic of influenza early in September led to the division here indicated. (3) From September 1 to December 31, 1918. These four months we have designated as the "Autumn Season" or the "Influenza Period."

THE WINTER OF 1917-18

The death rate in the army should be compared with that for the same age period in civil life. The comparison should be made on the records for the same year and the same season. Through the help of the Health Commissioners of certain cities we are able to do this. Most enlisted men in the army were between 21 and 31 years of age. The period nearest this available in civil statistics is the age between 20 and 29 years. In comparing these figures there is a slight disadvantage to the

army on each of the following points: (1) The death rate in the group from 20 to 29 years of age is lower than that of the draft age from 21 to 31 years. (2) The death rate in these ages is greater among males than among females. (3) The army includes more men above 31 than below 21. (4) The population of cities is as a rule overestimated and a slight overestimate in the population lowers the estimated death rate markedly.

With these explanations a comparison of the army death rate with the rates in certain cities, expressed as annual rates, is given for this period in Table 1.

TABLE 1

Annual Death Rate per 1000. (Age 20 to 29 Yrs., Time, Oct., Nov., Dec., 1917; Jan., Feb., Mar., 1918.)

Place	Death Rate
Army	9.1
New York City.....	5.5
St. Louis	5.5
New Orleans	10.4
Pittsburgh	6.2
Chicago	5.2

It is seen that the average death rate in the camps is higher than that of any city with the exception of New Orleans.

As is true of cities the death rate varied widely in different camps, as is shown in Table 2.

TABLE 2

Annual Death Rate per 1000

National Guard		National Army	
Wheeler	28.3	Pike	30.7
Beauregard	25.4	Johnson	19.9
Bowie	23.1	Funston	16.3
Sevier	15.5	Travis	15.3

National Guard		National Army	
Cody	12.7	Lee	10.8
Doniphan	11.9	Dodge	9.1
Shelby	8.6	Taylor	9.0
Kearney	8.1	Gordon	7.8
Sheridan	2.8	Sherman	5.4
Hancock	2.6	Upton	5.3
Wadsworth	2.5	Custer	5.1
McClellan	2.4	Lewis	4.1
Logan	2.3	Meade	3.9
		Grant	3.8
		Devens	3.7
		Dix	2.9

By comparing tables 1 and 2 it will be seen that 13 camps had a lower death rate than New York and St. Louis for the age group of 20 to 29 years and in some this rate was about one-half that of these cities.

The diseases responsible for the greatest number of deaths in the army during the period now under consideration are the acute respiratory diseases. These are named in the order in which they caused death as follows: pneumonia, meningitis, measles, scarlet-fever and diphtheria. With the addition of tuberculosis these caused 77 per cent. of all deaths. Sixteen per cent. were due to other diseases and seven per cent. to mechanical injuries. Assuming the conditions in the registration area for 1915 to be fairly representative of other years we may express the relative fatality between civilian and army life during the six winter months as follows:

Pneumonia was 12 times greater in the army.

Meningitis was 45 times greater in the army.

Measles was 19 times greater in the army.

Scarlet-fever was 6 times greater in the army.

Diphtheria was 2 times greater in the army.

Tuberculosis was 13 times greater in civil life.

The low tuberculosis rate is due to the elimination of those in the active stage of this disease and most of the deaths from

this cause were due to the activation of latent stages by acute respiratory diseases,

By comparing the morbidity and mortality in our army during the six months of 1917-18 with the records for the first six months of the Civil War it appears that the advance in medicine and sanitation has prevented one half million cases of disease and some ten thousand deaths. During the Spanish-American War the annual death rate from typhoid fever in our camps per 100,000 was 879; during the six months of 1917-18 it was 1.3. In 1898 there was not a regiment in the United States Army which did not suffer from typhoid fever and in most regiments from 10 to 20 per cent. of the strength acquired this disease. In 1917-18, twelve divisions had not a case. If typhoid fever had prevailed in our camps in 1917-18 to the same extent as it did during the same time in the State of Delaware there would have been in the army over 50,000 cases and more than 5000 deaths from this disease alone. The morbidity from typhoid fever in Camp Dix, the mobilization camp for Delaware troops, was less than four times the mortality from this disease among civilians of that State. And if the mortality among the civilians had been calculated for the group included in the draft age there would be but little difference between the figures indicating morbidity from typhoid in Camp Dix and mortality from the same disease among the civilians. It is quite certain that every case of typhoid that occurred in our camps during the winter of 1917-18 was due to the fact that the man reached the camp and received his typhoid vaccination after he had already contracted the disease. There is no evidence that there was a case infected in any camp. The degree of protection furnished by this vaccine will be discussed later.

In the winter of 1917-18 our large camps were occupied by National Guard and National Army troops, the former in tents and the latter in barracks. The figures given in Table 2 show that this difference in quarters had no recognizable effect on the death rate. It is desirable at this point to set before the reader the information contained in Table 3.

TABLE 3

Location of National Guard and National Army Camps, Together with
the States from which Men are Drawn

October, 1917, to March, 1918

NATIONAL GUARD

Camp	Site	Source of Troops
Beauregard ...	Alexandria, La.	Arkansas, Louisiana, Missis- sippi
Bowie	Ft. Worth, Tex.	Oklahoma, Texas
Cody	Deming, N. M.	Iowa, Minnesota, Nebraska, South Dakota
Doniphan	Ft. Sill, Okla.	Kansas, Missouri
Hancock	Augusta, Ga.	Pennsylvania
Kearny	Linda Vista, Cal.	Arizona, California, Colorado, New Mexico, Utah
Logan	Houston, Tex.	Illinois
McClellan	Anniston, Ala.	Delaware, District of Colum- bia, Maryland, New Jersey, Virginia
Sevier	Greenville, S. C.	North Carolina, South Caro- lina, Tennessee
Shelby	Hattiesburg, Miss. ...	Indiana, Kentucky, West Vir- ginia
Sheridan	Montgomery, Ala. ...	Ohio
Wadsworth ...	Spartanburg, S. C. ...	New York
Wheeler	Macon, Ga.	Alabama, Florida, Georgia

NATIONAL ARMY

Custer	Battle Creek, Mich...	Michigan, Wisconsin
Devens	Ayer, Mass.	Maine, New Hampshire, Ver- mont, Massachusetts, Rhode Island, Connecticut, New York
Dix	Wrightstown, N. J. ..	Delaware, New Jersey, New York
Dodge	Des Moines, Iowa. ..	Illinois, Iowa, Minnesota, North Dakota
Funston	Ft. Riley, Kan.	Arizona, Colorado, Kansas, Missouri, Nebraska, New Mexico, South Dakota

 NATIONAL ARMY — *Continued*

¹ Gordon	..... Atlanta, Ga.	..... Alabama, Georgia, Tennessee
Grant	..... Rockford, Ill.	..... Illinois, Wisconsin
Jackson	..... Columbia, S. C.	..... Florida, North Carolina, South Carolina
Lee	..... Petersburg, Va.	..... Pennsylvania, Virginia, West Virginia
Lewis	..... American Lake, Wash.	..... Alaska, California, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming
Meade	..... Annapolis Junc., Md.	..... District of Columbia, Maryland, Pennsylvania
Pike	..... Little Rock, Ark.	..... Alabama, Arkansas, Louisiana, Mississippi
Sherman	..... Chillicothe, Ohio	..... Ohio
Taylor	..... Louisville, Ky.	..... Illinois, Indiana, Kentucky
Travis	..... F. Sam Houston, Tex.	..... Oklahoma, Texas
Upton	..... Yaphank, L. I., N. Y.	..... New York

NOTE: The States indicated represent the chief source of troops at each place. There are small increments from other points in a number of camps.

¹ This camp was occupied by the troops indicated less than two months, when these troops were sent to Wheeler and replaced at Gordon by draft men from many States.

By comparing Tables 2 and 3 it may be seen that climate had no recognizable influence on the death rate. Take a map of the United States and locate the camps. It will be found that those with high, intermediate and low death rates enjoy much the same climate; for example, Wheeler, rate 28.3; Jackson, 19.9; Sevier, 15.5; Hancock, 2.6 lie in the same region. Now, take another map and locate the camps not where they are but in the region from which their troops come. Then, it will appear that that portion of the United States east of the Mississippi, and north of the Ohio and Potomac rivers contains no camp with an annual death rate of 8 per 1000. Moreover, every camp with similar low death rate, with two exceptions, lies in this area. One of the apparent exceptions, Camp Gor-

don, is really not an exception. On the second map it also should be moved to this region (see footnote to Table 3.) Lewis is the only real exception. Why did the soldiers from this great north-eastern section of the United States bear the camp diseases of the winter of 1917-18 better than those from other sections of our country? Are they physically superior men? No, the draft records show their physical inferiority. Moreover, the per cent. of rejections in the draft was larger in this section than in either the South or West. There is one answer to this question and it is to my mind quite satisfactory. The diseases which caused the greatest number of deaths in our camps during that winter were the acute respiratory diseases already mentioned and which we may properly denominate "Crowd diseases." The section designated is the most densely populated part of our country, and a larger proportion of the men coming from it had acquired a greater degree of resistance to these diseases than was possessed by their more rural comrades. Before mobilization of the army the pneumonias, as the vital statistics show, were urban diseases, reaping their greatest harvests in the crowded cities. Those who had lived under urban conditions had acquired a degree of immunity not possessed by those who had never come in contact with the bacteria which cause these diseases.

While difference in susceptibility to the acute respiratory infections influenced the death rate between divisions, it was equally in evidence among the organizations of the same division.

Camp Cody reports that disease incidence was 48 per cent. higher in the 134th Infantry than in the 133rd. The latter was made up of troops from the larger cities of Iowa. The former included troops mainly from the smaller towns of Nebraska.

Similarly, disease incidence was 51 per cent. greater in the 136th Infantry made up from the smaller towns of Minnesota than in the 135th Infantry made up of men from the larger cities of this State.

The excess among rural troops of such diseases as measles,

mumps and scarlet fever has been observed at Camp Custer and at Camp Wheeler.

Camp Wadsworth reports that their division made up of Guardsmen from the larger cities of New York State was practically free from disease until March when about 1500 draft men from the mountains of Tennessee and Kentucky were received. Their arrival had a marked effect upon the disease rate. These men soon developed meningitis, pneumonia and the minor communicable diseases. Their non-effective rate was three times that of the original division.

The epidemiologist at Camp Doniphan points out the unusually low disease incidence among city troops as compared with those from the country. The 138th Infantry and 128th Machine Gun Battalion were recruited from St. Louis, Missouri. Their annual pneumonia morbidity rates from October to March were 15 to 25 respectively. The 137th Infantry and 129th Field Artillery were from the small towns of Kansas. Their corresponding rates were 65. and 50. respectively.

Of course the men who lived through the winter of 1917-18 in our large camps became thoroughly urbanized so far as concerned their reactions to crowd diseases. There is probably no city in the world in which contact between individuals is so close and so intimate as in a large military camp. It is generally believed that the greatest dangers from over crowding, so far as the spread of disease is concerned, are found in the sleeping quarters. This certainly was not true of our camps. The most dangerous contact is during the waking hours, at mess, at drill, in canteens, in assembly halls, when every one is coughing and each inhaling the spray from his neighbor. There is no evidence that cramped sleeping quarters played an important rôle in the spread of disease in our camps. Indeed, some camps with the most crowded sleeping quarters had low death rates. The writer was in an assembly hall, with every one of quite 5000 seats occupied and it seemed that at least every other man was coughing. Measurements were made and it was found that the greatest possible distance be-

tween the noses of adjoining neighbors either laterally or from front to rear was less than 26 inches. The whole atmosphere was filled with the spray of coughing and no radical changes would have been secured by removing the walls and roof of the hall. In other words, men may be dangerously crowded, so far as exposure to disease is concerned, while out of doors, and moreover, camp crowding, when new men are being made into seasoned soldiers as quickly as possible, is a necessity and the morbidity and mortality resulting therefrom must be accepted as one of the conditions imposed upon itself by any nation which neglects military preparation until the last moment and then hastens to do what could be better done without such haste. Our draft men were assembled directly from their homes in their ordinary clothing, bearing multiple and varied infective agents, the clean brought into contact with the unclean, crowded on to troop trains and sent to camp. Not a troop train reached Camp Wheeler in the fall of 1917 which did not have one or more cases of fully developed measles, with unknown numbers of exposures, when it reached camp. The control of infectious diseases under these conditions is a different problem from that which the civilian health officer has to deal with in a more stabile population. These men should have been assembled in groups of not more than 30, bathed and barbered, clothed in sterilized uniform, held in quarantine for 14 days and sent to camp in these small groups and then held under quarantine for at least 10 days longer, before being allowed to mingle with other groups. But the exigencies of the situation did not admit of this procedure. The purpose was of necessity to convert civilians into effective soldiers as soon as possible and not to make a demonstration in preventive medicine and this was done more effectively and with less loss in sickness and death than has been accomplished in any previous war. At the beginning of the Civil War companies and larger organizations had to be disbanded and sent home temporarily after assembly, on account of outbreaks of infectious diseases.

THE SUMMER OF 1918

During this period the great majority of the men who occupied the camps during the preceding winter went to France and their places were filled by newly drafted men. Moreover, the plan of the preceding fall by which men from definite sections were sent to certain camps was abandoned and the different camps were devoted to training in special lines of service. One became an Artillery, another an Engineer camp, etc.

The proportion of seasoned men left in the different camps varied greatly and this had a marked influence on the death rate in the different camps in the fall of 1918.

The annual death rate per 1000 for the summer months was 5.7, practically the same as that of civilians in the age group 20-29 years during the winter months. For the corresponding five months of the summer of 1916 the death rate from all causes for this age group in civilian life is estimated at 4.6. Consequently the rate of 5.7 for the army is still a trifle above that of civilian life. This is a remarkable showing for although the army is composed of men selected on account of superior physical qualities and who might be expected to have a lower death rate than the average among those of their own age, still when we consider the hazard that is always associated with the mobilization of large numbers for military service, the rate of 5.7 for the Summer Season may be pointed to with pardonable pride.

During the summer season pneumonia continued to be the chief cause of death. However, the greatest mortality occurred during the months of April and May and was most manifest among new increments from civil life. Contrary to the experience of the preceding winter the pneumonias prevailed most extensively in the middle western camps. Measles was much less prevalent and was confined to new men because it had exhausted the susceptible material among the troops which had passed the winter in service. It was expected that typhoid fever and dysentery would be more in evidence dur-

ing the summer, but neither became epidemic. The annual death rate for typhoid fever during this season was 3.3 per 100,000. When we compare this with the death rate of 897 per 100,000 in the summer of 1898 we can have some appreciation of the great advance in the prevention of this disease which for many centuries has been the captain of the cohorts of death in the armies of the world. Even this showing would have been surpassed had not some men reached the camps in an infected state. Typhoid fever was prevented by the chlorination of the water supplies and by specific vaccination. Incidentally the first of these proceedings prevented dysentery, diarrhea and similar gastro-intestinal ailments. Although some of the camps were located in malarial districts, so efficient was the destruction of mosquitoes that there is no evidence that any soldier was infected by these pests in any camp. There were a few cases but all such brought the infection with them and proper treatment made short-shift of these undesired guests.

THE AUTUMN OF 1918

Early in September came the great pandemic of influenza with pneumonia. This is the most deadly pestilence which has ever visited us and it ranks high among the epidemics of history as is shown in Table 4.

Preventive medicine is making rapid progress. Malaria and typhoid fever, once the scourges of armies, are well in hand. Typhus is no longer an enigma but still requires close watching. The pneumonias remain and constitute at present the greatest cause of death in all armies. Protective inoculation against the pneumonias has been tried only recently, and the results are promising. The combination of influenza and pneumonia has been most distressing and disastrous both in military and in civilian populations. During the Autumn Season of 1918, civilian communities suffered greatly but on account of the high concentration of susceptible material in our camps, the death rate among soldiers has been higher than

TABLE 4
COMPARATIVE TOLL OF EPIDEMICS

Disease	Place	Year	Period	Population	Deaths During Period	Population Killed During Period	Killed per Month
1. Plague	London	1665	7 months	500,000	68,593	14	2.0
2. Yellow Fever	Philadelphia	1793	4 months	40,000	4,041	10	2.5
3. Influenza-Pneumonia ...	Camp Sherman ...	1918	7 weeks	35,100	1,073	3.1	1.9
4. Typhoid Fever	U. S. Army Camps.	1898	4 months	108,000	1,580	1.5	.38
5. Influenza-Pneumonia ...	U. S. Army Camps.	1918	4 months	1,500,000	21,500	1.4	.35
6. Typhoid Fever	Plymouth, Pa.	1885	1 month	8,000	114	1.4	1.4
7. Measles-Pneumonia	Camp Pike	1917	14 weeks	28,100	252	.90	.28
8. Influenza-Pneumonia ...	Philadelphia	1918	7 weeks	1,761,000	13,500	.77	.48
9. Cholera	London	1849	23 weeks	.....	.....	.51	.096
10. ¹ Influenza-Pneumonia ...	New York City.....	1918	7 weeks	5,740,000	14,700	.39	.24
11. ¹ Influenza-Pneumonia ...	Paris	1889-90	7 weeks	2,260,000	6,500	.29	.18
12. Cholera	St. James Parish, London ("Broad St. Well")	1854	17 weeks	318,000	700	.22	.056
13. ¹ Influenza-Pneumonia ...	New York City.....	1891	1 month	1,681,000	1,818	.11	.11
14. ¹ Influenza-Pneumonia ...	New York City.....	1890	1 month	1,631,000	1,370	.084	.084
15. Poliomyelitis	New York City.....	1916	5 months	5,602,000	2,407	.043	.009

¹ Mortality computed indirectly from excess deaths over the ordinary.

among civilians. No part of the world has escaped this great scourge. In the past, there have been pandemics, but none, so far as we have statistical evidence, has wrought such heavy destruction as this over so wide an area. Hitherto the pandemic of 1889-90 has been looked upon as the most widespread and probably the most fatal. At that time more than 40 per cent. of the population of Massachusetts was affected but the death rate was not so high. The pandemic of 1918, when compared with that of 1889-90 is estimated to have caused *six times as many deaths*.

During the four autumn months of 1918, 338,343 cases of influenza were reported to the Surgeon General. This means that in the camps of this country *one out of every four men had influenza*.

The combination between influenza and pneumonia during the fall of 1918 seems to have been closer and more destructive than in any previous pandemic. During the autumn season there were reported to the Surgeon General 61,691 cases of pneumonia. This means that *one out of every twenty-four men encamped in this country had pneumonia*.

During the same period 22,186 men were reported to have died from the combined effects of influenza and pneumonia. This means that among the troops in this country *one out of every sixty-seven died*.

This fatality has been unparalleled in recent times. The influenza epidemic of 1918 ranks well up with the epidemics famous in history. Epidemiologists have regarded the dissemination of cholera from the Broad Street Well in London as a catastrophe. The typhoid epidemic of Plymouth, Pa., of 1885, is another illustration of the damage that can be done by epidemic disease once let loose. Yet the accompanying table shows that the fatality from influenza and pneumonia at Camp Sherman was greater than either of these. Compared with epidemics for which we have fairly accurate statistics, the death rate at Camp Sherman in the fall of 1918 is surpassed

only by that of Plague in London in 1665 and that of yellow fever in Philadelphia in 1793.

The Plague killed 14 per cent. of London's population in seven months' time. Yellow fever destroyed 10 per cent. of the population of Philadelphia in four months. In seven weeks influenza and pneumonia killed 3.1 per cent. of the strength at Camp Sherman. If we consider the time factor, these three instances are not unlike in their lethality. The Plague killed 2 per cent. of the population in a month, yellow fever 2.5 per cent and influenza and pneumonia 1.9 per cent.

In four months typhoid fever killed 1.5 per cent. of the soldiers encamped in this country during the war with Spain. Influenza and pneumonia killed 1.4 per cent. of the soldiers in our camps in 1918 and it also covered a period of four months.

During the Winter of 1917-18, Camp Pike showed the highest death rate of the larger camps; this was due for the most part to pneumonia to some extent following measles. In fourteen weeks Pike lost 0.9 per cent. of its strength. This is about one third of Sherman's loss, but the deaths at Sherman occurred in one-half the time. In the Winter of 1917-18, Camp Beauregard showed the highest weekly incidence for measles. It amounted to an annual admission rate per 1000 of 2,700. In the fall of 1918 Beauregard had an influenza admission rate during one week of 15,000. The 1917 epidemic looks insignificant compared to that of 1918 and yet at the time it was regarded with grave concern. Philadelphia headed the large cities in influenza fatality in this country, losing 0.8 per cent. of its population. This is about one-fourth of the loss at Sherman.

The pandemic of influenza in 1918 seems to have been more closely associated with the pneumonias than appears in any previous pandemic. From reports sent to the Surgeon General's Office, it appears that uncomplicated influenza was not by any means a fatal disease and that the high death rate was due to the pneumonias which followed. Pneumonia is a serious disease at all times. Recent records for the United States

Army show that the case morbidity rate for this disease has been as follows during the different periods of the last two years:

The year of 1917.....	11.2 per cent.
6 Winter months 1917-18.....	23.1 per cent.
5 Summer months 1918.....	18.8 per cent.
4 Autumn months 1918.....	34.4 per cent.
(influenza period)	

It is not strange that once pneumonia secured a foothold in patients already weakened by influenza their chances of recovery were lessened.

The pneumococcus has been long regarded as the chief cause of pneumonia. Of this organism four distinct types are recognized in this country. The fourth type is in reality a heterogeneous group which includes many organisms which may cause pneumonia and yet whose agglutinations and other reactions have not been recognized with a sufficient degree of accuracy to be accepted as a means of identification. During the past year, it has been impressed upon us more forcibly than before that other organisms than the pneumococcus may cause clinical pneumonia. The streptococcus and the staphylococcus, at least certain varieties of these organisms, have produced clinical pneumonia in our camps. One reading the reports that have been sent in from army camps in all parts of the country is impressed by the lack of agreement as to the bacteriology which has been responsible both for influenza and the accompanying pneumonia. So far as influenza is concerned, the descriptions of the clinical symptoms agree. There is no question but that the same disease clinically has existed in Massachusetts, Kansas and California. In one place, however, the Pfeiffer bacillus, in another the streptococcus hemolyticus and in a third some form of the pneumococcus has been believed to be the cause of the disease. Suspicion has also been cast upon various strains of streptococcus, the micro-

coccus catarrhalis and the staphylococcus. In one laboratory there has been no difficulty in isolating the Pfeiffer bacillus from the throats of influenza patients; in another this organism has not been found and good reason is furnished to support the belief that the disease is of purely streptococcic origin. These differences of opinion with respect to the initial cause of the infection have existed to a like degree in the case of the pneumococcic organisms which have been recovered from the throats of the sick. One camp reports more of one type of pneumococcus than another. There is agreement merely in the excessive numbers of type four, but we must remember that this is only a "waste basket" group. Pneumococci which do not respond to reactions characteristic of type one, two, or three are placed in group four. It follows, therefore, that the information that type four has prevailed during the epidemic is not altogether satisfactory.

In the face of these contradictory reports, not only from army camps but from civilian laboratories as well, we are handicapped in determining the true cause of the disease. Basing our opinion on the information at hand, we make the following tentative statements:

1. Influenza is an acute, highly infectious disease of unknown origin, characterized by the production of a marked leucopenia which results in withdrawal of the natural defenses of the body and the opening up of the paths of invasion for other pathogenic organisms which may be present.

2. We are of the opinion that one reason for the variation in the manifestations and course of the disease in different communities has been due to difference in the combinations of organisms which have worked symbiotically with the specific cause of influenza. This accounts for the finding of one organism prevalent in one place and another organism dominant in another.

3. We are of the opinion that the epidemic of influenza which occurred in the fall of 1918 was not a new entity but a recurrence or reappearance in a more virulent form of a disease

which had prevailed in the various army camps during the previous year. Our justification for this statement is that there are many incidents of people who largely escaped the disease in the fall and who had experienced or lived through a similar but much milder epidemic during the previous spring. In other words, we may say the soldiers who had clinical influenza in camp prior to August and those who, although having no clinical manifestations of the disease, lived through such an epidemic, were less gravely affected when the more virulent organisms reached them in the fall.

4. We believe that the largest single factor influencing the spread of influenza is the susceptibility of the individuals among whom it has been introduced. If these individuals have been once attacked by the disease even in a mild form or lived through a mild epidemic without showing clinical symptoms, they suffer less when the disease is again introduced. Among communities not previously exposed to influenza, this disease has usually involved from 20 to 50 per cent. of the personnel. The exact number affected is determined by the number of people who are naturally immune or have secured immunity by previous exposure.

5. It appears that natural immunity gives way before exposure, over-work and fatigue, as was demonstrated years ago by Pasteur in his experiments on birds with anthrax. Likewise, it is possible for human beings to have their resistance lowered by exposure to unaccustomed environment so that although naturally immune, the standard of immunity is reduced to the point where the influenza virus gains admittance, and overcomes the lowered resistance.

6. We believe that not only the rapidity with which the disease spreads, but its virulence is in direct proportion to the density of the susceptible population. In communities such as army camps and large cities, the contact of individuals is so close and so intimate that even though extra precautions are taken it is quite impossible to prevent disease from ultimately reaching all persons. Precautions such as quaran-

tine, spreading out of the personnel, closing places of assembly, delay the progress of the disease but fail wholly to prevent it.

The death rate from disease was lower in the A. E. F. than in the camps in this country. The more susceptible had been eliminated by sickness or death before the Divisions proceeded to France. However, the rates for individual diseases showed some interesting variations both in morbidity and mortality. There was, quite naturally, but little measles in the A. E. F., for the simple reason that the susceptible material had been practically consumed in the camps in this country. On the other hand the morbidity from scarlet fever and meningitis was higher in the A. E. F. There were probably several factors involved in this. One of these was the greater difficulty in the early recognition of cases and in their speedy and effective isolation. We have no data concerning the prevalence of these diseases among the civilian and military population of France in areas occupied by our troops and consequently we cannot evaluate this factor. Typhoid fever and dysentery were constantly more prevalent in the A. E. F. The purification of drinking water in an active battle area must be unsatisfactory. Intense thirst drives men to drink water from any and every available source. Moreover, experience demonstrates that the protection against typhoid fever furnished by vaccination is not absolute and may be overcome by massive doses of the infection. While the morbidity rate from this disease in the A. E. F. at no time approached that of former wars it was quite constantly higher than in our home camps. No bacterial vaccination, not even one attack of the disease, gives unlimited protection. Typhoid, when it develops among the vaccinated, is in no constant and essential way different from the same disease among the unvaccinated. Complications and death rate are essentially the same in the two conditions.

Venereal diseases increased in every camp with each increment from the civilian population. Indeed, one can look at the venereal chart of any division and tell from its peaks just

when recruits were received. These diseases showed much higher rates in the home camps than in the A. E. F. While this curse was by no means eliminated in our armies in France, the low rate is a credit to the morals of our sons and the efficiency of medical officers.

Naturally there was but little malaria in the A. E. F. Those who came into the home camps bearing the parasites of this disease were for the most part sterilized with quinine before going to France.

Pneumonia was the most prolific cause of death in all our armies in every country and at all seasons. The morbidity rates from this disease ran from October, 1917, to September, 1918, about on the same level, crossing and recrossing, but never separating widely, in the A. E. F. and the home camps.

With the advent of the virulent influenza in September, 1918, both lines made an abrupt ascent, but the peak of the curve representing the home troops reaches nearly six times the height of that for the A. E. F. Why this great difference? The divisions constituting the A. E. F. in October, 1918, had occupied the home camps the winter before and had left their most susceptible men in the hospitals and cemeteries in this country when they went abroad. Those who filled the home camps in the fall of 1918 were for the most part recently drawn from their scattered homes in which they had never come in contact with the bacteria of crowd diseases. Our statistical data, morbidity and mortality curves, fail to give us the real facts. They do not show the relative percentage of immunes in the two bodies which we are comparing nor do they indicate the losses by sickness and death incurred in the transformation of new into seasoned troops.

Seasoned soldiers, as represented by our troops in France, bore even a new infection — that of influenza — better than their raw comrades in this country. This suggests that there exists a non-specific immunity, which is of value, but is transitory, fluctuating in its protective power and hardly comparable with specific immunity such as has been secured in typhoid

fever. At the present time one seems forced to conclude that the control of the pneumonias is most likely to be found in some form of vaccination and since these diseases are caused by multiple bacteria, the vaccine, must, as is the case in typhoid fever, be polyvalent.

THE RÔLE OF PSYCHOLOGY
IN THE WAR

XX

HOW PSYCHOLOGY HAPPENED INTO THE WAR¹

ROBERT M. YERKES

IT has been said that the application of psychology to advertising rendered it respectable and that its applications to war advertised it widely and favorably and created an unprecedented demand for its services. The name itself seriously interfered with early developments in the army because of very common misconceptions and confusions. Psychology meant to the average army officer something wholly intangible, even mysterious. He thought of its methods as akin to those of the spiritualist, the devotee of psychical research, or those of the "medium." There also occurred very naturally serious confusion of psychology with psychiatry in the minds of non-medical officers. This worked to the disadvantage of both subjects, because of their diverse aims, requirements, and

¹ The following reports present complete accounts of the various lines of psychological service in the army and the navy:

Psychology in Relation to the War, by Robert M. Yerkes. Psychological Review, Vol. 25, 1918, pp. 85-115.

Report of the Psychology Committee of the National Research Council. By Robert M. Yerkes. Psychological Review, Vol. 26, 1919, pp. 83-149.

Army Mental Tests. Edited by C. S. Yoakum and R. M. Yerkes. Pp. xiii-303. Henry Holt & Co., 1920.

Psychological Examining in the United States Army (official report). Memoirs of the National Academy of Sciences, Vol. XV., Washington, D. C. (in press).

The Personnel System of the United States Army. Vol. I, History of the Personnel System; Vol. II, The Personnel Manual. Published by the War Department, Washington, D. C., 1919.

relations. Fortunately alike for the science of psychology and the army, the practical work which is to be described in these chapters over-rode the disadvantages of its name and ultimately converted psychology into a word to conjure with in the United States Army.

There probably were few greater surprises in the war than the conspicuously important service of psychology. Aside from the few who were professionally engaged in the subject no one thought of the study of mental life as having any possible practical bearing on the problems of war. The writer well remembers listening to General Squier present before a meeting of the National Academy of Sciences in Washington in the spring of 1917 the necessity for the study of problems of military clothing. Among the many problems whose solution, in his judgment, would favorably affect the efficiency of our army there were several which the writer recognized as primarily psychological. It happens that neither the War Department nor the scientists of the country, through their instrument of organization, the National Research Council, succeeded in getting around to any of these problems, but had time sufficed and opportunity for such work appeared, psychologists would have coöperated with physiologists, and chemists and physicists, in the careful determination of kind and quality of materials to be used, most serviceable, sightly, and comfortable style and cut, and numerous other special characteristics of the assemblage of garments which constitute the soldier's outfit of clothing.

The National Research Council had made only small headway toward the solution of military problems before it met certain definite needs which called for the psychological expert. As a result a committee for psychology was organized and from that hour the psychologists of the country worked side by side with investigators representing the medical sciences, various branches of biology, anthropology, geology and geography, physics, chemistry and engineering. Throughout this large and heterogeneous group of investigators there ex-

isted a splendid spirit of coöperation and of appreciation of one another's efforts to serve.

One of the first obviously psychological problems which was brought to the attention of the National Research Council by the Government was the need of reliable methods for selecting the best men to serve as lookout and gun pointers on armed merchant vessels. This, like many other suggestions and requests for assistance from the navy and the army, was referred to a competent scientist, who finally succeeded in developing highly useful methods. It is fair to say that the efforts of psychologists to make themselves useful in the war were successful from the very start. The authorities of the National Research Council recognized this fact, but they were nevertheless greatly surprised, at first by the ambition of the psychological profession to help win the war, a little later by the psychologists' expectations of success, and finally by the actual achievements.

Even before war had been declared individual psychologists had been thinking of ways in which their science might be applied to military problems. On April 6, 1917, a group of experimental psychologists, then in session at Cambridge, Massachusetts, appointed a committee to consider the relation of psychology to military affairs and to further its application to practical problems. This was the beginning of concerted action. From that day the psychologists of the country acted unitedly as well as disinterestedly and whole-heartedly. In other countries psychologists served conspicuously, but always as individuals and seldom in their professional rôle.

The national psychological association of this country immediately interested itself in the question of service and committees were speedily appointed to work systematically on such important tasks as (1) the assembling and digesting of psychological literature relating to military affairs so that we might make use of the latest and the best information from all parts of the world; (2) the psychological examination of recruits; (3) psychological problems of aviation; (4) the selection of men

for tasks requiring special mental aptitude; (5) problems of recreation and amusement in the army and navy; (6) problems of vision; (7) pedagogical and psychological problems of military training and discipline; (8) problems of incapacity, including those of shell shock and reëducation; (9) problems of emotional instability, fear and inadequate self-control; (10) methods of influencing the morale of the enemy; (11) problems of hearing affecting military activities; (12) tests of deception.

This list will give the reader some idea of the range of interest in military problems which existed among psychologists even before they had had opportunity to observe directly the needs of the army and the navy. Altogether during the war more than a score of committees of psychologists furthered the applications of their science to the military situation. Most of them rendered effective service. But it was shortly discovered that committee action and the work of civilian psychologists would not suffice. In many instances, it was absolutely essential that the scientists who wished to serve even in their professional capacity should become parts of the military machine. There was no hesitation about accepting such responsibility, although it often entailed serious personal sacrifice. There existed everywhere faith in the possibility of usefulness, determination to serve successfully, and a desire to get together and coöperate effectively.

The spring and summer of 1917 saw little progress toward psychological military service beyond that of organization. There were few good leads and the unprejudiced observer of the activities of American psychologists might fairly have concluded that all their eagerness and busyness would contribute nothing to our military success unless these scientifically inclined individuals exchanged their habitually professional rôles for that of the combatant soldier.

By the middle of summer the situation began to change rapidly, for the War Department had become aware of certain possibilities of psychological service. The first successful approach by psychologists was made on the Medical De-



Figure 1. A trade test in the United States Army



Figure 2. An individual psychological examination in the United States Army

partment of the army through the National Research Council. This was rendered possible by the breadth of view, faith, and optimism of Colonel Victor C. Vaughan, Colonel William H. Welch, and Surgeon General William C. Gorgas. The second important contact, made a little later, was with the Adjutant General of the Army. This was due to the insight and energy, as well as the faith and enterprise, of Colonel W. D. Scott, Doctor E. L. Thorndike, Mr. F. W. Keppel, later Third Assistant Secretary of War, Secretary of War Baker and General McCain. Almost simultaneously relations were established with the navy through the National Research Council which enabled Doctor, subsequently Lieutenant Commander, Raymond Dodge to serve that branch of the military organization to excellent advantage over a period of nearly two years.

Thus during July, August, and September of 1917 the psychological war organization of the country was transformed into an effective military organization. It is true that psychologists were used both in the Medical Department of the army and in the office of the Adjutant General as civilians, but in the majority of cases the active members of the profession were ultimately given military appointment either in the army or the navy.

Viewed in retrospect the three principal lines of psychological service are: psychological examining, conducted under the direction of the Surgeon General of the Army and affecting all arms of the military service; the classification of personnel in the army, conducted under the Adjutant General, and similarly affecting the entire army; and, finally, the study of special psychological problems in the army and the navy. The principal achievements of psychologists in the military service will be presented in the following chapter under these three heads.

It would be almost as unfair to the army and the navy as to the psychologists of the country to make it appear that the development of really important service in this entirely untried field of application was agreeably easy. Instead it was at many

times and in various directions almost impossible. A few lines of work progressed from the start smoothly, steadily, and even rapidly. Others, equally deserving of success, met obstacles which were either insurmountable or wasteful of precious time. In many instances there were discouraging disapprovals and heartbreaking delays, misunderstandings and opposition, which wasted time of officers who should have been engaged in increasing military efficiency.

As a fitting introduction to the chapter on achievements a brief statement may be made concerning the psychological personnel for the three principal lines of service which have been mentioned.

For psychological examining, the War Department first authorized a preliminary trial of methods. In order to make this preliminary experiment about thirty well trained psychologists were given either military appointment in the Sanitary Corps or civilian appointment to work in National Army cantonments or in the office of the Surgeon General of the Army. After this preliminary work had satisfactorily demonstrated the practical value of results, psychological examining was rapidly extended to the entire army. For this purpose a large number of military psychologists were needed. A school for military psychology was promptly established at the Medical Officers' Training Camp, Fort Oglethorpe, Georgia, where properly qualified psychologists might be given intensive training in military drill as well as in army methods of psychological examining. During the existence of this school approximately one hundred officers and more than three hundred enlisted men were trained. At least two hundred of these may fairly be listed as professional psychologists. Many of these men served in the army either as civilian appointees or as soldiers for from one to two years. By some they have been stigmatized as "non-combatants" and have been subjected to the unfair criticism of choosing a safe service. It is only just to point out that a considerable number of the psychologists of the country preferred combatant service and were kept from such

service only by the insistence of administrative authorities that their professional services were incalculably more important to the army than their possible help as combatants.

The committee on Classification of Personnel in the army likewise organized special schools in which large numbers of personnel adjutants were trained and subsequently men for the conduct of trades tests.

Although psychological work received a large amount of unsought publicity during the war and many points of method were thus brought to the attention of lay readers, it may not be amiss to describe very briefly the principal methods of classification which were used by psychologists.

When a man is sent to a military training camp he has already passed the preliminary draft examination, but before he can qualify as a soldier he must also pass a rigid medical examination. Assuming that he qualifies on the basis of medical examination, the following additional information about him is necessary if the army is to assign him intelligently and use him to advantage. There is, first, measurement of his mental alertness or intelligence. This is supplied by the psychological examination. Second, the determination, by personal interview or by actual measurement, of the man's occupational training, experience, and proficiency. Assignment should always take into account physique, degree of intelligence, and occupational value, for the army is an extremely complex social organization which has need of almost all of the common occupations engaged in by civilized man, and, in varying proportions, of all of the grades of intelligence and degrees of physical development and endurance which men possess.

If the best possible use is to be made of an individual in the army, and for that matter anywhere else in society, he must be placed where his physical qualifications can be used effectively, where his intelligence is adequate but not wasted, and where his special occupational training and experience are needed. To put a well educated, highly intelligent young fellow who is gifted with the power of leadership into the ranks

to serve as a private is inexcusably wasteful, and, on the other hand, to commission as an officer a man of meager education, less than average intelligence, and mediocre ability as a leader is a criminal blunder.

The army needed (and it was quick to recognize the need), these several sorts of information about each man. It needed also the sort of machinery which would make use of this information in assigning and training men. The ideal course of things, toward which events moved rapidly during the progress of the war ran somewhat as follows: There was, first, reliable rating of a man and resulting classification in accordance with physical characteristics, mental ability, and occupation. In the light of this information he was assigned to his place in the military machine. He was then, if things fell out properly, suitably and efficiently trained and instructed in the duties of a soldier. Subsequently he was skilfully controlled and directed, inspiringly led and heartened in the day's work, and technically as well as socially supported both in the drudgery of drill and in the demands of action.

The theory of psychological service was that human factors should be appreciated, measured, and intelligently used, that so far as feasible chance, personal whim or bias, and convention should be replaced by action in the light of reasonably accurate and thorough information. In a word, that the army should utilize what may be called "human engineering," just as it attempts to utilize other forms of engineering which have to do primarily with non-living things.

Methods of psychological examining suitable for use in the army were not available at the beginning of the war, but they were prepared speedily by a small group of experts in much the same fashion that the Liberty Motor was developed; that is, by intensive, highly coördinated work based upon the best information that could be assembled from all available sources. The group of psychologists charged with the development of methods promptly decided that it would be entirely too slow

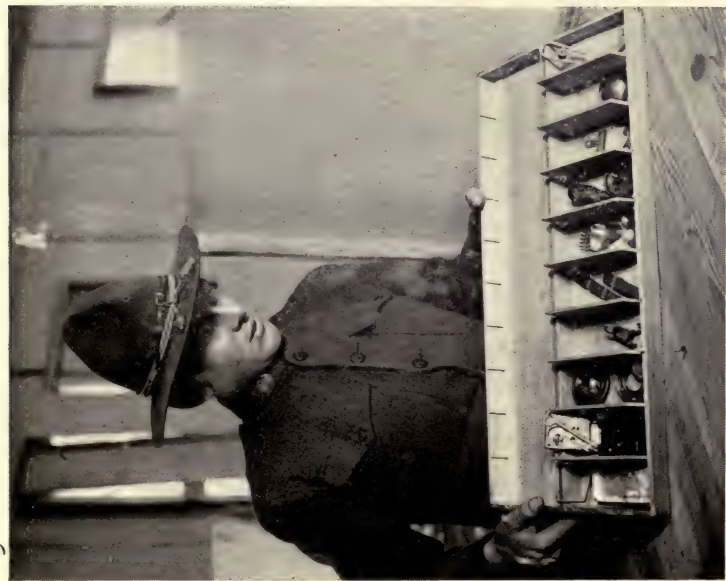


Figure 3. Testing the mechanical skill of soldiers by the Stenquist method



Group of soldiers at Camp Lee, Virginia, taking the army psychological examination for literates. This was before benches were provided in the examining room!



Soldiers scoring psychological examination papers

Figure 4

EXAMINATION ALPHA

a process to examine soldiers individually and that consequently the only feasible procedure was examination by large groups. Group methods were therefore prepared and methods of individual examining were arranged to supplement as necessary the use of the group methods. The methods finally adopted and used throughout the army differ in many respects from those originally prepared and recommended. They may be described very briefly as follows:

There are four principal systems or stages in the examination. First comes the procedure of segregation, by means of which the original group, which may, if examining rooms permit, include as many as five hundred men, is split into two sub-groups: (a) the literates, men who can speak and read English fairly well, and (b) the illiterates, men who are relatively unfamiliar with the English language. These two groups must necessarily be treated somewhat differently, therefore the literates are given a group examination known as Alpha, which consists of eight markedly different tests. This examination, although it requires almost no writing on the part of the subject, does demand facility in using written and oral instructions. The illiterate group is given an examination known as Beta, which is in effect Alpha translated into pictorial form. In this examination pantomime and demonstration supplant written and oral instructions.

Each group examination requires approximately fifty minutes. Subjects who fail in Alpha are ordinarily given opportunity to improve their ratings by taking Beta, and subjects who fail in Beta are given individual examination in order that they may be more accurately and justly rated than in the group examination alone.

Any particular individual may have to take one, two or three of these types of examination. Thus, for example, a man of low grade literacy who happens to get into examination Alpha may also have to take Beta and some form of individual examination.

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FORM 5

GROUP EXAMINATION ALPHA

GROUP NO. _____

Name _____ Rank _____ Age _____

Company _____ Regiment _____ Arm _____ Division _____

In what country or state born? _____ Years in U. S. ? _____ Race _____

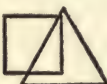
Occupation _____ Weekly Wages _____

Schooling: Grades, 1. 2. 3. 4. 5. 6. 7. 8: _____ High or Prep. School, Year 1. 2. 3. 4: _____ College, Year 1. 2. 3. 4. _____

TEST 1

1. ○ ○ ○ ○ ○

2. ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨

3. 4. 

5. ○ ○ ○ Yes No

6. ○ ○ ○ ○ ○

7. A B C D E F G H I J K L M N O P

8. ○ ○ ○ MILITARY GUN CAMP

9. 34-79-56-87-68-25-82-47-27-31-64-93-71-41-52-99

10.

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11.

7F	△ 4	○ 3	△ 5A	○ 8	□ 2	△ 6	○ 9B	□ 3
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12. 1 2 3 4 5 6 7 8 9

Division of Psychology, Medical Department U. S. A.
 Authorized by the Surgeon General, Feb. 8, 1918, Edition, Feb. 14, 1919, 100,000.

Figure 4. The first test of the group examination for literate soldiers, known as army Alpha.

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FORM 0 **GROUP EXAMINATION BETA** **GROUP NO.** _____

Name _____ Rank _____ Age _____

Company _____ Regiment _____ Arm _____ Division _____

In what country or state born? _____ Years in U.S.? _____ Race _____

Occupation _____ Weekly Wages _____

Schooling: Grades, 1, 2, 3, 4, 5, 6, 7, 8: High or Prep. School, Year 1, 2, 3, 4: College, Year 1, 2, 3, 4.

TEST 8

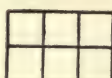
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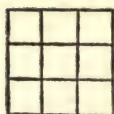
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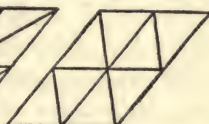
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7.



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9.



10.



11.



12.



Division of Psychology, Medical Department, U. S. A.
Authorized by the Surgeon General, Feb. 6, 1918, Edition, July 10, 1918, 300,000

Figure 5. The eighth test of the examination for illiterate soldiers, known as army Beta.

Examination papers for both Alpha and Beta are scored rapidly by the use of stencils and the resulting rating is promptly reported to the appropriate military authority.

By means of this system of examinations it is possible for an examining staff consisting of four psychologists and a force of scoring clerks to examine as many as one thousand men per day.

Every man examined by one or more of the procedures described is assigned a numerical rating and in addition a letter grade which indicate his general intellectual ability or mental alertness. The numerical rating is used only for statistical purposes, the letter grade for practical military purposes. The latter alone is reported ordinarily to military officers and recorded on the soldier's service record and qualification card.

The letter grades which are in use are defined as follows: A, designates very superior intelligence; B, superior intelligence; C +, high average intelligence; C, average intelligence; C —, low average intelligence; D, inferior intelligence; D —, very inferior intelligence. The letter E has been reserved for the designation of men whose mental ability is seemingly inadequate for regular military duty.

Commissioned officers usually possess and obviously should possess A or B intelligence. Many excellent non-commissioned officers possess C or C + intelligence, but in the main this group is composed of men with C + or B ratings. The great body of privates grades C. Men with D or D — intelligence are usually slow to learn and rarely gain promotion. Many of them, especially the D — individuals, cannot be used to advantage in a military emergency which demands rapidity of training. The results of army mental testing indicate that the majority of D — and E soldiers are below ten years mental age. A few fall as low as three or four years.

The contrast between A and D — intelligence becomes impressive when it is shown that men of A intelligence have the requisite mental ability to achieve superior records in college

or professional school, whereas D — individuals are rarely able to pass beyond the third or fourth grade of an elementary school, however long they may attend.

The methods developed for the classification of personnel under the Adjutant General of the Army and for the solution of special problems are entirely too varied for description here. In the first instance they are primarily adaptations of business methods, many of which were improved and supplemented by the application of psychological knowledge and experience.

In the case of special psychological problems it was usually a matter of analyzing the military situation carefully and of drawing upon the resources of psychological laboratories, or more often of psychological skill, for the particular variety of apparatus or technique which promised to solve the problem. Ingenuity was at a premium, but it could not be used successfully until the military situation had been skilfully analyzed and its important factors or requirements brought into clear light. Several psychologists were eminently successful both in analysis and in devising or adapting methods to cover the results of analysis.

XXI

WHAT PSYCHOLOGY CONTRIBUTED TO THE WAR

ROBERT M. YERKES

WITH the preceding chapter on methods as an introduction, an attempt will be made in the present chapter to state very briefly what psychology accomplished during the war. It is impossible to give a complete account of the work, but results and practical applications may be sampled in such a way as to give the reader a fair idea of the nature and significance of this new kind of military service.

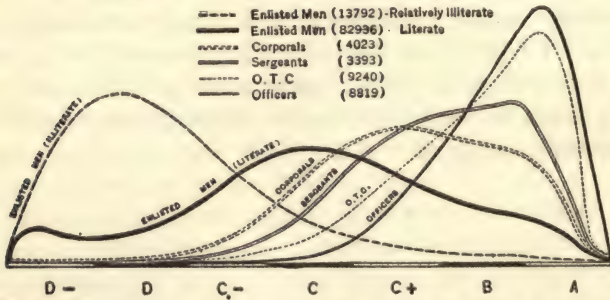


FIG. 1.—DISTRIBUTION OF INTELLIGENCE RATINGS IN TYPICAL ARMY GROUPS, SHOWING VALUE OF TESTS IN IDENTIFICATION OF OFFICER MATERIAL. ILLITERATE GROUP GIVEN BETA; OTHER GROUPS, ALPHA.

Figure 1. Distribution of intelligence grades for typical army groups.

The first thing which appeared in the results of the psychological examination of soldiers was remarkable difference in the intelligence of individuals and of army groups. This fact was no surprise to psychologists, but it created a profoundly important impression in the minds of military officers who were relatively unfamiliar with methods and results of mental measurement. The two figures, 1 and 2, will suffice to indicate

the extent of these differences. The one of these figures, 1 represents the distribution of the various grades of intelligence in such important military groups as enlisted men, non-commissioned officers (corporals and sergeants), students in officers' training camps (O. T. C.), and officers. The letter grades, as has already been stated in the previous chapter, designate from A to D — degrees of intelligence which range all the way from very superior (A) to very inferior (D —). Commissioned officers of the United States Army, with few exceptions, possess superior or very superior intelligence. A few of the good officers fall in the C + class and a still smaller number, almost invariably unsatisfactory to the service, possess only average intelligence, designated by the letter C. By contrast with the officers, illiterate enlisted men usually possess inferior intelligence. Many of them are very inferior and relatively few rise above the high average represented by C +. The average literate enlisted man possesses that middle grade ability which is designated by C.

Another method of representing differences in intelligence between important military groups is used in Fig. 2. In this case the several grades are thrown into three groups which may be designated conveniently high, medium, and low. It is noteworthy that commissioned officers are found only in the medium and high groups, that students in officers' training camps, who by virtue of this fact are candidates for appointment as officers, occasionally fall in the **low intelligence** groups. White recruits are rather more frequently found in the low than in the high groups, although the great majority of them are of medium intelligence. Those soldiers who are least satisfactory for military service and most expensive are more often than not found to have low intelligence. The figure in question roughly represents the results for four such groups: disciplinary cases, men ranked by their officers as poorest in their company, men of low military value as judged by their officers, and unteachable men.

The results of psychological examination as sampled by these

two figures indicate the distribution of intelligence which existed when psychological work was undertaken. The meaning of this distribution is that by various selectional processes, more or less cumbersome, time-consuming, and expensive, highly intelligent men become commissioned officers, somewhat less able

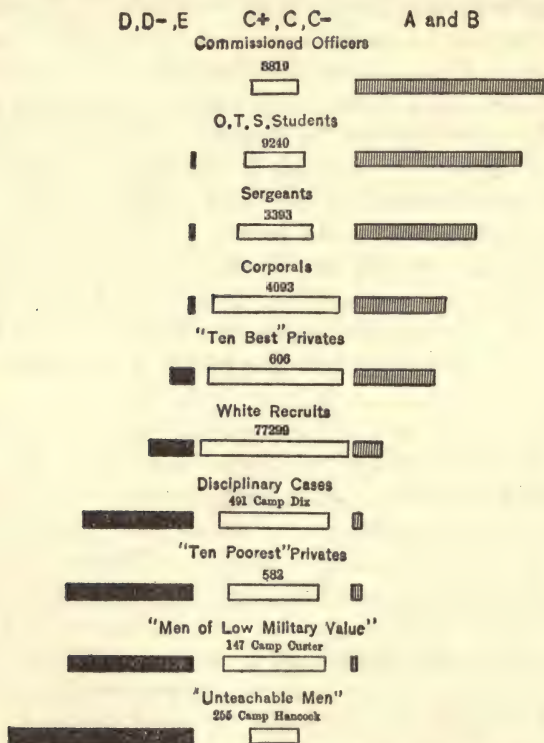


Figure 2. The proportions of low, average, and high grade men in typical army groups.

men become sergeants or corporals or excellent privates, while the least intelligent of all worry along as poor privates or as relatively unteachable.

Army officers to whom such results as these were presented saw the point immediately and, admitting marked differences

in intelligence among men, they went right to the practical point by asking the psychologist what relation intelligence has to the ways of using men in the army and to general military value. Luckily it was not difficult to answer this question definitely and satisfactorily and that not by the statement of some psychologist's opinion but by the presentation of results of measurements made in the army itself and exhibited in their relations to the judgments of experienced officers. A number of pictures of these results will enable the reader to grasp quickly the significant points.

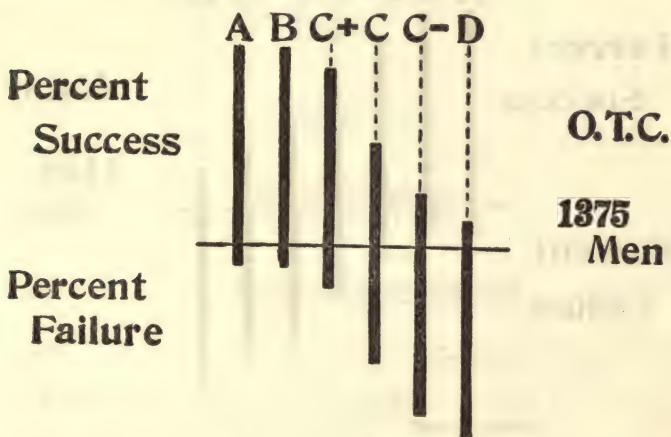


Figure 5. The relation of intelligence to success and failure in officers' training schools.

Figures 5 and 6 indicate the relation of intelligence to success and failure in officers' training camps and in non-commissioned officers' training camps. Again, it should be emphasized that the students in these camps had been admitted prior to psychological examination and practically without reference to their intelligence. The psychological ratings were obtained and subsequently were compared with the records of success and failure in the schools. It is notable that in both types of school, the proportion of failures increases steadily

and rapidly from the very superior group to the very inferior group. In fact, the chance that a man rated as A in intelligence will fail is just about the same as the chance that a man who is rated D in intelligence will succeed in the work of the school. Almost all of the A and B groups and fully three-fourths of the C + group pass. Almost all of the inferior or very inferior men fail in the officers' training schools, although a considerable proportion succeed in passing the examinations for non-commis-

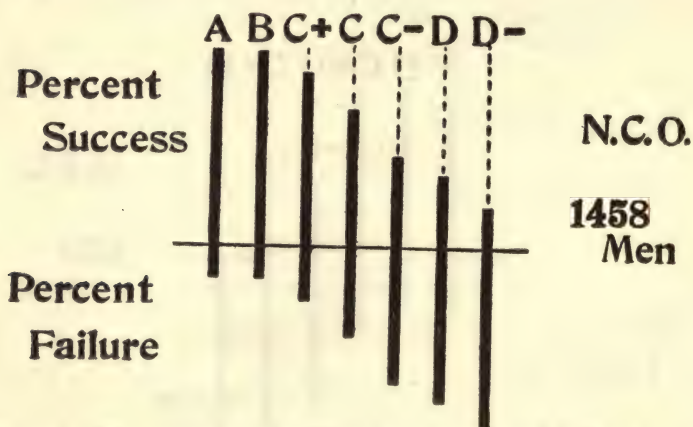


Figure 6. The relation of intelligence to success and failure in non-commissioned officers' training schools.

sioned officers. These figures make it clear that if men were admitted to such schools partly on the basis of intelligence a considerable saving could be effected. The rule might reasonably be made that no men grading below C— in intelligence should be admitted to an officers' training school, and similarly that no men grading lower than D in intelligence should be admitted to a non-commissioned officers' school.

Turning for a moment to an entirely different sort of evidence, we have in Fig. 7 the results of officers' ratings compared with intelligence ratings. In this instance nearly four hundred men of twelve different companies were rated by their

officers on their general value to the service as very poor, poor, fair, good, or best. These same men were independently rated by psychological examiners. The average degree of intelligence in each of the five groups is roughly represented by the length of the heavy line and by the numerical rating printed

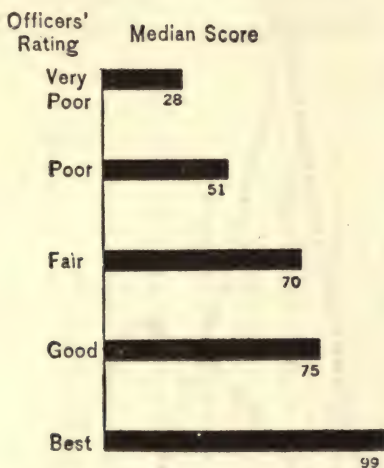


Figure 7. The median intelligence scores (by points) of groups of soldiers who were rated by their officers as "very poor" to "best" in military value.

beneath each line. Thus, for example, whereas the intelligence of men rated as very poor is indicated by the number 28, that of men designated as best is indicated by 99. The contrast is unquestionably significant and it is clear that the army would have profited greatly had the very poor group been excluded from service on the basis of intelligence measurements.

A similar picture is presented in Fig. 8, which indicates the contrast between men judged of low military value by their officers and the complete draft quota from one of the camps. The most common grade of intelligence in the unsatisfactory group is slightly above D; that is, inferior, whereas for the entire draft quota the most common grade is between C and C+.

In the preliminary trial or stage of psychological examining it was discovered only by accident that companies and regiments which were built up in the ordinary military fashion without

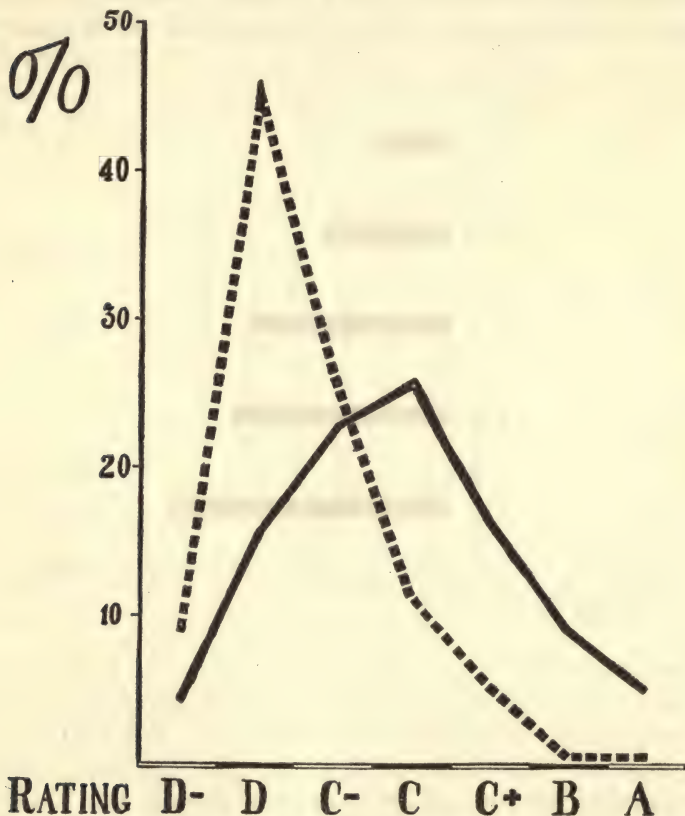


Figure 8. The intelligence of men of low military value as compared with that of the complete draft quota for a certain camp.

special reference to the intelligence of the men differed extremely, both as to average intellectual ability and the distribution of the different grades of ability. This fact finds expression in Fig. 9, which represents the proportions of high

grade and low grade men in the several companies of an infantry regiment. The intermediate grades of intelligence are omitted as irrelevant and the figure represents the percentage of A and B men in each company, and, by contrast, the percentage of men who are illiterate or of foreign birth. The first of these groups is, in the long run, highly valuable because of ease of training, general adaptability, and service-

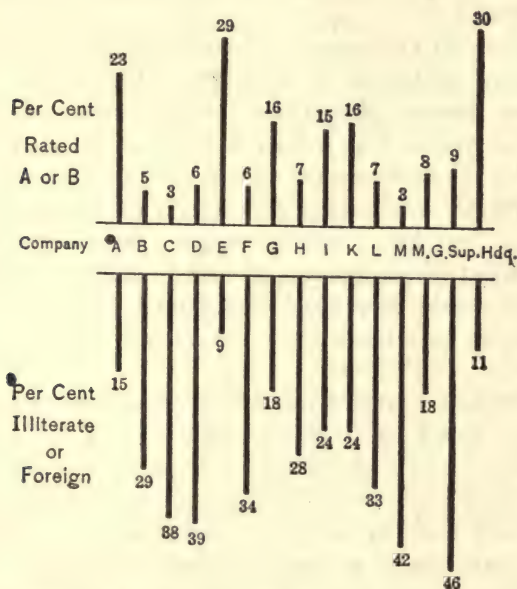


Figure 9. Inequalities of intelligence among the companies of an infantry regiment.

ability for responsible tasks. The second is generally undesirable from the officers' point of view because it requires more time and patience for training, supplies relatively few men for the duties of officers or for other responsible tasks and, in a word, is often extremely difficult to train satisfactorily because of a certain proportion of very slow, dull, or unwilling men.

The contrast between C company and E company in this

particular regiment is startling. The one has three per cent. of highly intelligent men; the other, twenty-nine. The one, thirty-eight per cent. of illiterate or foreign-born soldiers; and the other, only nine per cent. Yet the captains of these two companies are expected and required by their commanding officer to produce in the shortest possible time practically equivalent fighting machines. The captain of C company has by comparison with the captain of E company an extraordinarily difficult task.

It required no arguments to convince army officers of the undesirability of this state of affairs. Indeed they had no sooner been shown such pictures for companies, batteries, and regiments as that of Fig. 9 than they demanded reorganization in order that the various units should have approximately equal mental strength and similar distribution of intelligence. Beyond this it was but a step to suggest, then to request, and finally to effect the assignment of men to organizations so that intelligence should be properly distributed, or if not properly distributed, at least much more satisfactorily distributed than formerly.

In some divisions of the United States Army the use of mental ratings was based upon specifications for different types of organization. It was decided, for example, that the infantry regiment could use a certain percentage of low grade men and that it should have for efficient training and action a certain minimum percentage of men of high intelligence. These specifications naturally differed somewhat for different types of organization. Their principal values were the facilitation of training and the avoidance of such inequalities of distribution as have been described.

The evidences of the practical relations of intelligence to military value which have been presented up to this point are primarily objective, but it must be admitted that the phenomenal success of this sort of psychological service in the army was due in part to the opinions of officers. Usually these opinions

were based upon more or less satisfactory evidences of practical usefulness.

Following the official trial of psychological methods in four National Army cantonments during the fall of 1917, the opinions of officers concerning the value of the results was sought and it was found that nearly 75 per cent. were favorable to the continuance of the service. Somewhat more than a year later similar inquiries in many divisional training camps indicated that this percentage had increased to 90. Of thirty statements received from commanding officers of camps or divisions twenty-seven were definitely favorable and many of them exhibited keen interest in the work and a desire to further its development.

The following statements, chosen almost at random, are representative :

The psychological work done and being done by Captain —— in this camp has been consistently good and has proven of much practical value.

At first, due to the innate conservatism of line and even medical officers, his task was a rather uphill one; but now, largely due to his own energy and tact, and to the thoroughness and honesty of his work, practically all officers here have been convinced of its practical value and unique assistance in rating, sorting, and disposing of the divers kinds of men as well as officers who pass through such a camp.

In addition to his ordinary duties of testing and rating the personnel of organizations, he has been employed in making numerous special examinations, where the handling and disposition of men whose cases involved obscurities of mental and physical peculiarity or weakness were in question. The lucid solving of such human problems by the methods of his peculiar art and his personal acuteness and persistence have often relieved such perplexities.

I consider such an expert and his specialty among the most useful aids lately given the army toward the scientific and non-wasteful utilization of man power.

And from another officer :

I am of the opinion that the psychological service is an excellent thing.

During the present war officers are thrown in contact with large numbers of other officers and enlisted men, to whom they are complete strangers. It is impossible to quickly form a knowledge of any one's ability. Time, personal association or accident may show that a certain officer or enlisted man is worthy of advancement. We are constantly looking for intelligent men. The psychological test gives us something to start on, and I have used these psychological ratings on many occasions in the absence of a knowledge of the individual concerned. While I am firmly of the opinion that the psychological rating is excellent among new men, it does not take the place of the final judgment formed of an individual by personal contact and observation under difficult conditions. I would, therefore, consider it of the greatest importance for a just test of new men to subject them first to the psychological test. The final decision with reference to men who have passed such test will depend upon the result of the judgment formed of the individual after sufficient time had elapsed during which they were under observation. From my experience in different camps, I am of the opinion that enlisted men who rate below A and B class should not be considered as candidates for the officers' training schools.

The extent of the service of psychological examining and its relation to military efficiency and expenditures have not thus far been appreciated, chiefly because the public has been ignorant of the facts. The following summary statements are taken from the official report of the service :

The work of mental examining was organized finally in 35 army training camps. A grand total of 1,726,966 men had been given psychological examination prior to January 31, 1919. Of this number about 42,000 were commissioned officers. More than 83,500 of the enlisted men included in the total had been given individual examination in addition to the group examination for literates, for illiterates, or both.

Between April 28, 1918, and January 31, 1919, 7800 (0.5 per cent.) men of the 1,556,011 examined were reported for discharge by psychological examiners because of mental inferiority. The recommendations for assignment to labor battalions because of low grade intelligence number 10,014 (0.6 + per cent.). For assignment to development battalions in order that they might be more carefully observed and given preliminary training to discover, if possible, ways of using them in the army, 9487 (0.6 + per cent.) men were recommended.

During this same interval there were reported 4780 men with mental age below 7 years; 7875, between 7 and 8 years; 14,814, between 8 and 9 years; 18,878, between 9 and 10 years. This gives a total of 46,347 men under 10 years' mental age. It is extremely improbable that many of these individuals were worth what it cost the government to maintain, equip, and train them for military service.

Psychological examiners were not responsible for discharges. They merely reported on the intelligence of each soldier. It remained for the medical officer and the commanding officer of camp or division to decide what should be done. Certainly a considerable proportion, although by no means all, of the men who were too inferior in intelligence to be worth training for military purposes were discharged. It is probable that no less than 50,000 men were designated by psychological examiners for discharge, for service in labor organizations, or for assignment to development battalions. Most of these men were so inferior in intelligence that they could be trained only with extreme pains and very slowly. Well above 10,000 of them, possibly as many as 15,000, possessed less intellectual ability than the average eight-year-old child.

Assuming that the psychologists discovered 10,000 men not otherwise discovered, who, because of low grade intelligence, were not suitable for regular military service, and assuming further that the cost to the United States Government of equipping, training, and sending a soldier over-seas was approximately \$2500, it is a simple matter of arithmetic to determine

that \$25,000,000 would be expended on this next to useless human material if it were not either rejected or promptly discharged on the discovery of the mental condition.

By contrast with this possible saving it is interesting to know that it cost the government less than 50c. per man to conduct psychological examinations. Thus it would appear that on the basis of rejection or discharge alone, leaving out of account possible increases of rapidity of training and in military efficiency by reason of better placement of men and more satisfactory selection of commissioned officers and non-commissioned officers, the service of psychological examining might have saved the United States Government, had it been used to the utmost throughout the war, many millions of dollars.

Of the many unexpected and startling results of psychological examining in the army only a few can be mentioned. First in importance is the frequency of illiteracy in this country. It was originally assumed by psychological examiners that at least nine in ten of the young men who had been drafted could read and write English well enough to take the written group examination. But, as a matter of fact, more than twice this number, that is above 20 per cent., were so inexpert in reading and writing that they could not do themselves justice in an examination which required either. It is undoubtedly safe to say that one-quarter of the drafted men are, or rather were at the time they were mustered into the service, incapable of reading and writing English to a really useful extent. They could merely speak it. There is a lesson in this exhibition of illiteracy which the government and the people of the United States will not be slow to appreciate and to profit by.

A second fact which was brought into clear relief by the wholesale examining of colored and white men in the draft is the intellectual inferiority of the negro. Quite apart from educational status, which is utterly unsatisfactory, the negro soldier is of relatively low grade intelligence. The accompanying table presents the contrast of white with black in respect to the distribution of intelligence. This also is in the nature of

a lesson, for it suggests that education alone will not place the negro race on a par with its Caucasian competitors.

	Number of Cases	Intelligence Grades						
		A	B	C+	C	C—	D	D—
White officers	15,385	55.9 %	28.5 %	12.5 %	3.3 %	0.4 %	0 %	0 %
White draft...	94,002	4.1 %	8.0 %	15.2 %	25.0 %	23.8 %	17.0 %	7.1 %
Negro draft...	18,691	0.1 %	0.6 %	2.0 %	5.7 %	12.9 %	29.7 %	49.0 %

Officers of different arms of the military service are surprisingly unlike in nature and degree of intelligence. Comparison of the data for engineers with those for medical officers indicates at once differences of two sorts: the engineers make higher scores in each test but almost without exception the higher their score in a particular test the lower the score for the medical officers. The chaplains differ markedly from both the engineers and the medical men, especially in the departure of their scores from the standard (50 percentile). These great differences for important professional groups of officers may be due either to heredity or to education and experience. In the former case they will probably prove to have important vocational significance; in the latter, similarly important educational significance.

Of the many other interesting discoveries concerning the relations of intelligence to race, to length of residence in the United States, to education, to fitness for military service, to age, and to military rank, nothing can be said here because this is a chapter and not a book. But, in view of its quite exceptional practical importance, the relation of intelligence to army occupations may be described very briefly.

In the course of psychological examining it became apparent that the intelligence of men of different occupations varied not only with the individual but also in quite as definite a way with his occupation. The intelligence ratings of groups representing

some sixty occupations which occurred in the army were, therefore, brought together. The principal facts are indicated in

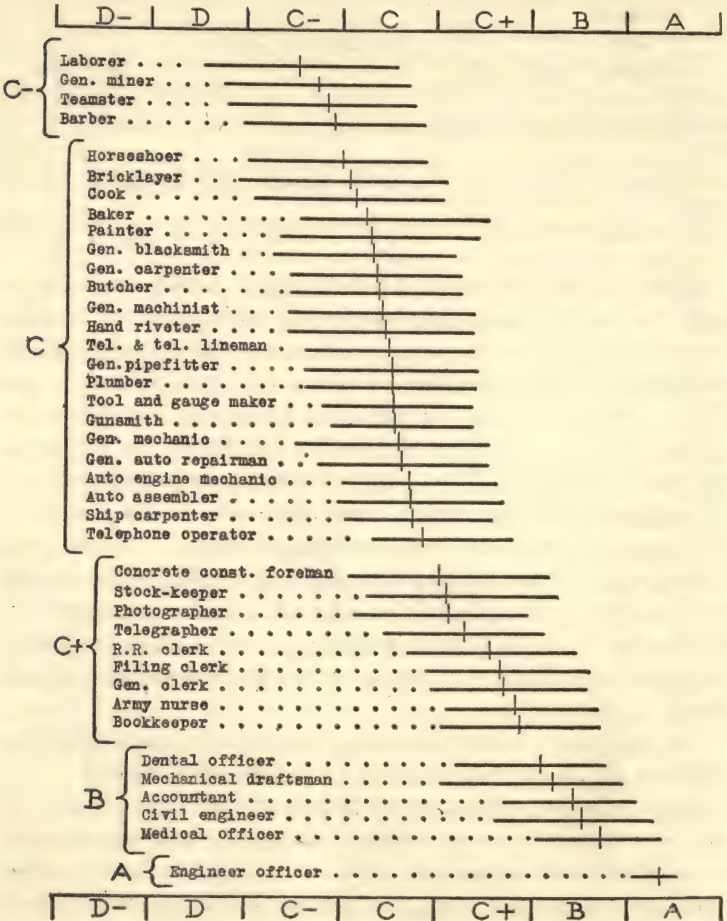


Figure 10. Occupational intelligence standards, showing the relation of soldiers' intelligence to their occupations.

Fig. 10, which represents the distribution of intelligence of the middle fifty per cent. in each occupation. The vertical cross-

bar indicates for a given occupation the median intelligence. It is not difficult to discover important relations of these facts to vocational guidance.

Consideration of army occupations naturally brings us to the second main division of this chapter, which is the classification of personnel in the army with respect especially to occupation or trade and its military usefulness.

In the summer of 1917 a group known as the Committee on Classification of Personnel in the Army was organized by the War Department to work under the immediate direction of the Adjutant General of the army. For the work of this committee an initial appropriation of \$25,000 was made and, as the success of its work led to the constant increase of its responsibilities, additional appropriations were approved until the total amounted to more than three-quarters of a million.

The big task of this committee was the occupational classification and placement of enlisted men. Officers charged with personnel duties were placed in all army divisions, depots, training camps, and various other stations. A special card system was devised to render available information concerning the educational, occupational, and other military qualifications of every man. With a minimum of clerical work this system was used to select nearly a million soldiers for transfer to such technical units as the engineers, aviation, the ordnance, and other staff corps, and for the transfer of even more men within divisions or camps. Approximately 450 officers and 7000 men were engaged in this work. The number of soldiers interviewed by trained members of the personnel staff and classified according to army usefulness approximated three and one-half million.

The allotment branch or central clearing-house of the committee in Washington received from the camps information about the numbers of skilled tradesmen in each contingent of the draft and assisted in distributing these men among the various camps in accordance with their supply of skilled workers. Up to November 11, 1919, requests for about 600,000

men with definite occupational qualifications had been filled. Thus the committee materially aided in securing the most profitable distribution or placement of the members of essential occupations.

As a further aid in assignment the committee prepared definitions of the several hundred different trades needed in the army and brought them together in a book known as "Army Trades Specifications," which became indispensable for staff corps and personnel officers in securing skilled men.

Tables were prepared which show in detail the needs for skilled workers in each kind of battalion, company, regiment, or other military unit. These tables were carefully studied, criticized, and after repeated modification, approved by army units in France, and they later served as a basis for the rapid organization of divisions. From these occupational tables there finally developed a system of personnel specifications for the enlisted men of four hundred different types of organization.

Qualification cards for officers were devised and put into general use. These, like the similar cards for enlisted men, supplied a complete record of educational, occupational, and military experience, and, in addition, a rating by superior officers. These cards were filed in Washington and duplicates were supplied to division commanders for their assistance in assigning their officers.

A uniform system of rating commissioned officers was developed. This was first installed in the officers' training camps as an aid in selecting candidates for commissions. Later it was used also in selecting from among candidates for admission to the schools. In the same direction definitions of the duties and qualifications of no less than 500 different kinds of officers in the various arms of the service were prepared under the direction of the committee. These specifications for commissioned officers are used in locating officer material, in selecting men for training as officers, and in assigning officers to duty. Important studies on the basis of the data secured by the committee have been made concerning the significance of age, edu-

cation, civil earnings, intelligence, and certain other qualifications of officers in the different corps and arms of the service.

The Committee on Classification of Personnel coöperated with several other departments or divisions within the military establishment, thus helping to coördinate its important activities with closely related work and at the same time steadily increasing the efficiency of methods of handling personnel.

But most interesting and perhaps most important of all of the achievements of this successful committee was the trades' test. The prospective importance of this achievement for American industry is so considerable that the work will be described at much greater length than the other and more strictly military tasks of the group. The following account of the development of trade testing within the army is quoted from "Measuring a Workman's Skill; the Use of Trade Tests in the Army and Industrial Establishments," which was prepared by Lt. Col. W. V. Bingham for the National Society for Vocational Education:

"The development of trade testing has been one of the useful by-products of the war. It had long been recognized that waste of human life and human skill through misplacement in the army or in industry is a futile, costly extravagance; yet it requires the stress of war to make people act on this conviction that the conservation of carpenters, welders, and turret lathe operators is really more important than the conservation of water power and timber land, and that rich returns would accrue to an investment of money and talent directed toward an improvement of the technique of human classification and placement. Of the improvement in personnel technique, which has emerged from army experience, perhaps no phase has greater promise of worth for industry than the development of standardized trade tests.

"The standardized trade tests were first introduced into army practice last June [1918] when there was pressing need, especially for the truck driver's and auto mechanic's tests, to determine whether the ammunition and supply trains of the divisions

that were about to be sent to France really had the skilled personnel necessary to get the supplies up to the front under battle conditions. By the time that mobilization ceased in November, standardized tests in about eighty of the more important trades were in use.

“The cost of production and standardization of the tests was on the average roughly a thousand dollars a trade. But as it worked out, this was an extremely economical investment for the War Department. A conservative estimate was made last October of the saving in the cost of pay and subsistence of recruits, which was at that time being effected as a direct result of the use of these trade tests. Data gleaned from the twenty cantonments in which the trade test stations were operating, indicated that in each station the tests were saving the Depot Brigade personnel officers from making about ten erroneous assignments a day. Since it takes at least two weeks on the average to discover that a soldier, who has been sent to a technical unit is not fully competent and to effect the necessary replacement, each avoidance of such a mistake meant a saving of \$42. The trade tests were then saving the army about \$210,000 a month on this item alone. But of course the real economies were not of money but of time. Correct initial placement meant speedier organization and more rapid progress of training. Trade tests had their share in the rapid shaping of army units which were ready ahead of schedule to meet the demands of Foch and Pershing on the western front.

“In devising a standardized trade test it is first necessary to study the trade to find out through analysis of typical jobs, what are the elements of skill and information and judgment which combine to constitute real proficiency. The Army Trade Test Division began by assembling information from such sources as the archives of the U. S. Department of Labor, state and city civil service commissions, and the like. Suggestive typical tasks and numerous trade questions and answers were accumulated through conference with officials of trade unions that maintain standards of proficiency among their membership,

and also from employment managers of large establishments. But no amount of this accumulated material could take the place of analysis made by actual observation of skilled and partly skilled tradesmen at their work.

“ After analysis of the trade comes construction of a tentative test. This sometimes takes the form of a performance test, a job arranged so as to require of the candidate a demonstration of his manual proficiency and his judgment in the use of the main tools of his trade.

“ Other tests are entirely oral, consisting of questions to elicit definite bits of trade knowledge, to sample the range of the candidate's practice, and to try the soundness of his judgment on typical matters.

“ A third type of test, similar in principle to the oral test, presents to the candidate pictures of tools, machines, materials and products of his trade, and requires him to identify them and to indicate uses. Thus in one of the horseshoer's tests are included pictures of a fullered horseshoe and a stamped horseshoe; a shoe to prevent interfering, and a toe weight shoe; a pad and a hoof plate, a mule shoe, a winter shoe, and a racing plate. Besides identifying these or telling differences in their use, the candidate is shown pictures of, and asked to name or tell the use of, a pritchel, clinch tongs, a fitting hammer, a driving hammer, and a buffer; a straight hardie and a round hardie; a cold chisel and a hot chisel; a hoof expander, a toe calk, and other things familiarity with which is found to differentiate the more experienced from the less experienced horseshoer. Pictures of horses' feet in various conditions enable the candidate to show his good judgment as well as his trade knowledge, by telling how each should be treated. The examiner, keeping an exact score on the candidate's responses and referring to the standard ratings, can in ten minutes assure himself with reasonable accuracy as to whether the soldier knows as much about the horseshoeing trade as most experts, journeymen, apprentices, or novices, as the case may be.

" Similarly, in an oral test for horseshoers, the soldier is asked such questions as these:

" ' How does a deep-seated corn usually show on a sole? ' ' Red, ' is the answer which experienced horseshoers universally give to this answer.

" ' What is the fullering in a shoe? ' ' Groove ' and ' crease ' have both been found to be acceptable answers.

" ' How do you shoe a horse that has a bone spavin? ' ' Lower the toe and raise the heels. '

" Questions likely to provoke narration of processes or descriptive answers that are both time-consuming and difficult to evaluate, are omitted. Only those questions are included which seem simple, clear, direct and unambiguous, and which promise to elicit answers that can be accurately scored and that will be genuinely diagnostic of trade proficiency.

" After a tentative test containing sixty, eighty, or even a hundred distinct elements has been assembled it must be tried out. It is first used in testing from five to twenty men whose high proficiency in the trade is known. During this preliminary tryout the test undergoes progressive revision and refinement. Ambiguities and localisms of terminology are eliminated. Elements that require too much time or that prove to be repetitive of other elements, or that are not sufficiently diagnostic, are dropped.

" The revised test is now subjected to a second and much more thorough tryout. With adherence to rigorously uniform procedure, it is administered in various establishments and in different industrial regions of the country, to no less than eighty men whose proficiency is known. Of these, twenty are experts in the trade, twenty are journeymen, and twenty are men rated as apprentices of at least fourteen months and less than three years' standing. The remaining twenty are novices, persons of good education and intelligence but with no experience at the trade in question. The testing of these novices is necessary in order to discover and eliminate the elements of the test which

an educated non-tradesman could pass, on the basis of his general knowledge or intelligence.

“ All of these test records, which show exactly what each of the eighty or a hundred men did with every element of the test, are turned over to the statistician who computes for every element its diagnostic value. He then chooses those elements which are found to differentiate most sharply between novice and apprentice, apprentice and journeyman, or journeyman and expert. He determines the best numerical weighting to be attached to each of these selected elements. And finally, combining these scores, he ascertains the critical rating which is found to separate the largest number of known apprentices, from the novices, the journeymen from the apprentices, and so on. This stage of the process we have called ‘calibrating’ the test. Like the calibration of a thermometer, the critical points of the test score are located, not by theory or by the opinion of the deviser of the test, but by actual trial. Only thus are we confident that the test will really measure trade proficiency with the degree of reliability required by the army.

“ Not infrequently the tentative formulation of the test has proved inadequate, and after all the labor and expense of an elaborate tryout it had to be thrown into the waste-basket and a fresh start made. Only after a test had been devised which was found on thorough trial to measure up to the requirements, was it turned over for use with the soldiers.

“ While these trade tests were being developed, two astonishing discoveries came to light. The first of these is the rarity, the practical nonexistence, of the exclusively motor-minded type of tradesman, the man who can do the job with his hands but cannot tell you about it in words. In beginning the trade test development we had expected to meet numerous difficulties due to the prevalence among manual laborers of this variety of mental constitution. We expected to find that the oral type of tests would prove useful with the more verbally minded men; but we anticipated meeting many tradesmen of high

proficiency and skill who could do little or nothing with these oral questions. This expectation proved to be wholly at variance with the facts. The problem here suggested, as to whether the so-called pure type of motor-mindedness is really only a mythical abstraction, is respectfully referred to the laboratories of educational psychology.

"The other discovery, not wholly unrelated to the first, was the fact that in a majority of the trades the oral tests yielded more accurate differentiations of proficiency than did the performance tests. In other words, the journeyman and the expert differ from the apprentice not so much because they have greater manual skill and dexterity as because they excel in judgment, technical information, or trade knowledge.

"Of course this is not the case in some occupations, such as truck driver or typist. Here oral tests are futile. The candidate must be given a chance to demonstrate his skill through actual performance. But in most of the trades the actual performance testing of the man on the manual job can be omitted without great loss to our knowledge of the man's proficiency."

Finally, the third chief division of this chapter should present the work of psychologists on special military problems. Many such were formulated by officers of the army, by scientific men in the National Research Council, and by psychologists who were in the midst of military duties. In the majority of instances the attempts to deal with special problems were conspicuously successful, in that they yielded immediately serviceable results.

There are no better examples to be found to illustrate problems, methods, and achievements, than the work of Lieutenant Commander Raymond Dodge, who has already published elsewhere fascinating accounts of the professional work of military psychologists.

4 We quote from an article on "Mental Engineering," prepared by this officer for the American "Review of Reviews" (May, 1919):

Let me illustrate this kind of war work by a single concrete instance in which the details are not military secrets. The first problem that was referred to the sub-committee on vision was the question whether we had any way of selecting those naval recruits who could be trained most quickly as gun-pointers for the armed merchant ships.

The first step was to learn exactly what a gun-pointer had to do. The next was to reduce the more or less complicated processes of gun-pointing to their simplest neuro-muscular terms. It was a definite problem for analysis; and, because of the perfect systematization and high specialization of naval tasks it was relatively simple. The third step was to adapt approved scientific technics to the study of this particular complex of neuro-muscular processes. For this purpose an instrument was devised that would show all the following facts on a single record line: 1, the time that it took a sailor to start his gun-pointing reaction after the target at which he was aiming started to move; 2, the accuracy with which he was able to "keep on" the moving target; 3, the time that it took him to respond to a change in the direction of motion of the target; 4, the ability to press the firing key when he was on; 5, the effect of firing on his pointing. (See frontispiece.)

All these data were so simplified that they could be accurately estimated from simple measurements of a single line without elaborate computations. A succession of records indicated the probable quickness with which the sailor would learn the new coordinations. The final step was to test the probable military value of our instrument and its records by performances of expert and inexpert gun-pointers.

The first trials proved the usefulness of the device. It clearly differentiated between the qualified gun-pointers, the partially trained, and the untrained. It picked a number of promising novices and indicated the faults of some who were slow to improve. Predictions based on the records were uniformly corroborated by subsequent experience. Somewhat later it was possible to construct a robust training instrument along similar lines that was rather enthusiastically reported on by various naval officers, and was widely reproduced by the navy for use in the Naval Training Stations.

At a time when every available gun was needed for service

afloat, the utility of our relatively simple and inexpensive training instrument that closely reproduced the coördinations of actual service needs no emphasis.

In the navy, precisely as in the army, the solution of one problem almost inevitably led to the formulation of numerous related problems. The task thus became endless and at the same time intensely exacting as well as stimulating. In a summary official report to the National Research Council Lieutenant Commander Dodge writes as follows concerning the relation of his study of problems of gun-pointing to other tasks:

In view of these reiterated suggestions, and in view of the wide scope of the permission granted me by the Honorable Secretary of the Navy to visit the fleet for analysis of the naval tasks, I undertook to do for the plotting room what I have done for gun-pointing. After observing the various tasks of the plotting room, I tried to reduce them to their simplest psychological terms, then to devise corresponding test methods, and finally to combine them in a single form or blank that would disclose at a glance, without elaborate computation, the relative fitness of the several recruits for plotting room service.

The tests finally recommended were: the ability to repeat clearly by telephone, a series of ordinary commands that were received by telephone, the ability to remember and repeat numerals, to read a circular scale, to read a plotting scale and to lay off distances to scale, together with neatness and accuracy in drawing and sub-dividing simple geometrical figures. All these data, except the telephone test, were arranged on a single blank which could be estimated at a glance as good, medium, and poor.

Again in an entirely different connection the psychologist's skill was found serviceable in selecting men to be trained as listeners for anti-submarine work.

One of the minor but necessary tasks of the Training Section of the Bureau of Navigation was to find properly equipped men for the new Listeners' School without robbing other training schools of their regular quotas. It was a relatively simple problem in the economy of human material and personnel, but one for which

no data were available. At the request of Captain Bennett U. S. N., Chief of the Training Section, I analyzed the requirements of the Listeners' School.

On the basis of that analysis, I elaborated a series of tests for candidates for the Listeners' School and was sent to various training stations to pick students from the enlisted personnel. After correcting the tests from the school experience with the first few quotas, I was able to make a detailed recommendation for the examination of candidates. With the cordial assistance of naval medical officers in the several districts, these tests afforded the Listeners' School a selected student personnel from which 80 per cent. to 95 per cent. of each class passed the course, all without seriously affecting the supply of suitable men for other naval schools.

Space fails us to describe similarly the psychological problems relating to the intelligence service in the army, the aviation service, the chemical warfare service, for all of which important tasks were undertaken.

RELATIONS OF THE WAR TO PROGRESS IN
SCIENCE

XXII

THE POSSIBILITIES OF COÖPERATION IN RESEARCH

GEORGE ELLERY HALE

NO one can survey the part played by science in the war without reflecting on the ultimate influence of the war on science. Able investigators have been killed or incapacitated, and with them a host of men who might have taken high places in research. Sources of revenue have been cut off, and the heavy financial burdens permanently imposed upon individuals, institutions, and governments must tend to reduce the funds available for the advancement of science. On the other hand, the usefulness of science is appreciated as it never has been before, and some newly enlightened governments have already recognized that large appropriations for research will bring manifold benefits to the state. The leaders of industry have also been quick to appreciate the increased returns that research renders possible, and industrial laboratories are multiplying at an unprecedented rate. The dearth of available investigators, and the higher salary scale of the industrial world, have seriously affected educational institutions, members of whose scientific staffs, inadequately paid and tempted by offers of powerful instrumental equipment, have been drawn into the industries. On the other hand, industrial leaders have repeatedly emphasized the fundamental importance of scientific researches made solely for the advancement of knowledge, and the necessity of basing all great industrial advances on the results of such investigations. Thus they may be expected to contribute even more liberally than before to the development

of laboratories organized for work of this nature. Educational institutions are also likely to recognize that science should play a larger part in their curriculum, and that men skilled in research should be developed in greatly increased numbers. The enlarged appreciation of science by the public, the demand for investigators in the industries, and the attitude of industrial leaders of wide vision toward fundamental science, should facilitate attempts to secure the added endowments and equipment required.

On the whole, the outlook in America seems most encouraging. But the great advance in science that thus appears to be within reach cannot be attained without organized effort and much hard work. On the one hand, the present interest of the public in science must be developed and utilized to the full, and on the other, the spirit of coöperation that played so large a part during the war must be applied to the lasting advantage of science and research. Fortunately enough, this spirit has not been confined within national boundaries. The harmony of purpose and unity of effort displayed by the nations of the Entente in the prosecution of the war have also drawn them more closely together in science and research, with consequences that are bound to prove fruitful in coming years.

The Honorable Elihu Root, who combines the wide vision of a great statesman with a keen appreciation of the importance and methods of scientific research, has recently expressed himself as follows:

Science has been arranging, classifying, methodizing, simplifying everything except itself. It has made possible the tremendous modern development of the power of organization which has so multiplied the effective power of human effort as to make the differences from the past seem to be of kind rather than of degree. It has organized itself very imperfectly. Scientific men are only recently realizing that the principles which apply to success on a large scale in transportation and manufacture and general staff work apply to them; that the difference between a mob and an

army does not depend upon occupation or purpose but upon human nature; that the effective power of a great number of scientific men may be increased by organization just as the effective power of a great number of laborers may be increased by military discipline.

The emphasis laid by Mr. Root on the importance of organization in science must not be misinterpreted. For many years he has been President of the Board of Trustees of the Carnegie Institution of Washington, and an active member of its Executive Committee. Thus kept in close touch with scientific research, he is well aware of the vital importance of individual initiative and the necessity of encouraging the independent efforts of the original thinker. Thus he goes on to say :

This attitude follows naturally from the demand of true scientific work for individual concentration and isolation. The sequence, however, is not necessary or laudable. Your isolated and concentrated scientist must know what has gone before, or he will waste his life in doing what has already been done, or in repeating past failures. He must know something about what his contemporaries are trying to do, or he will waste his life in duplicating effort. The history of science is so vast and contemporary effort is so active that if he undertakes to acquire this knowledge by himself alone his life is largely wasted in doing that; his initiative and creative power are gone before he is ready to use them. Occasionally a man appears who has the instinct to reject the negligible. A very great mind goes directly to the decisive fact, the determining symptom, and can afford not to burden itself with a great mass of unimportant facts; but there are few such minds even among those capable of real scientific work. All other minds need to be guided away from the useless and towards the useful. That can be done only by the application of scientific method to science itself through the purely scientific process of organizing effort.

It is plain that if we are to have effective organization in science, it must be adapted to the needs of the individual worker, stimulating him to larger conceptions, emphasizing the value of original effort, and encouraging independence of action,

while at the same time securing the advantages of wide coöperation and division of labor, reducing *unnecessary* duplication¹ of work and providing the means of facilitating research and promoting discovery and progress.

A casual view of the problem of effecting such organization of science might lead to the conclusion that the aims just enumerated are mutually incompatible. It can be shown by actual examples, however, that this is not the case, and that an important advance, in harmony with Mr. Root's conception, is entirely possible.

It goes without saying that no scheme of organization, effected by lesser men, can ever duplicate the epoch-making discoveries of the Faradays, the Darwins, the Pasteurs, and the Rayleighs, who have worked largely unaided, and who will continue to open up the chief pathways of science. Even for such men, however, organization can accomplish much, not by seeking to plan their researches or control their methods, but by securing coöperation, if and when it is needed, and by rendering unnecessary some of the routine work they are now forced to perform.

Let us now turn to some examples of organized research, beginning with a familiar case drawn from the field of astronomy, where the wide expanse of the heavens and the natural limitations of single observers, and even of the largest observatories, led long ago to coöperative effort.

In the words of the late Sir David Gill, then Astronomer Royal at the Cape of Good Hope, the great comet of 1882 showed "an astonishing brilliancy as it rose behind the mountains on the east of Table Bay, and seemed in no way diminished in brightness when the sun rose a few minutes afterward. It was only necessary to shade the eye from direct sunlight with a hand at arm's length, to see the comet, with its brilliant white nucleus and dense white, sharply bordered tail of quite half a degree in length." This extraordinary phenomenon, more brilliant than any comet since 1843, marked the beginning of

¹ Some duplication is frequently desirable.

celestial photography at the Cape of Good Hope. No special photographic telescope was available, but Sir David enlisted the aid of a local photographer, whose camera, strapped to an equatorial telescope, immediately yielded pictures of exceptional value. But even more striking than the image of the comet itself was the dense background of stars simultaneously registered upon these plates. Stellar photographs had been taken before, but they had shown only a few of the brighter stars, and no such demonstration of the boundless possibilities of astronomical photography had ever been encountered. Always alive to new opportunities and keen in the appreciation of new methods, Sir David adopted similar means for the mapping of more than 450,000 stars, whose positions were determined through the coöperation of Professor Kapteyn of Groningen, who measured their images on the photographs.

Stimulated by this success, the Henry Brothers soon adopted photographic methods for star charting at the Paris Observatory, and in 1887 an International Congress, called at Sir David's suggestion, met in Paris to arrange for a general survey of the entire heavens by photography. Fifty-six delegates of seventeen different nationalities resolved to construct a photographic chart of the whole sky, comprising stars down to the fourteenth magnitude, estimated to be twenty millions in number. A standard form of photographic telescope was adopted for use at eighteen observatories scattered over the globe, with results which have appeared in many volumes. These contain the measured positions of the stars, and are supplemented by heliogravure enlargements from the plates, estimated, when complete for the entire atlas of the sky, to form a pile thirty feet high and two tons in weight.

The great coöperative undertaking just described is one that involves dealing with a task that is too large for a single institution, and therefore calls for a division of labor among a number of participants. It should be remembered, however, that a very different mode of attacking such a problem may be employed. In fact, although the difference between the two methods may

seem on first examination to be slight, it nevertheless involves a fundamental question of principle, so important that it calls for special emphasis in any discussion of coöperative research.

One of the great problems of astronomy is the determination of the structure of the sidereal universe. Its complete solution would involve countless observations. Nevertheless, Professor Kapteyn, the eminent Dutch astronomer, resolved many years ago to make a serious effort to deal with the question. In order to do so, as he had no telescope or other observational means of his own, he enlisted the coöperation of astronomers scattered over the whole world.

In organizing his attack, he recognized that the inclusion of only the brighter stars, or even of all those contained in the International Chart of the Heavens, would not nearly suffice for his purpose. He must penetrate as far as possible into the depths of space, and, therefore, thousands of millions of stars are of direct importance in his studies. Moreover, it is evident that if he were to confine his attention to some limited region of the sky, he could form no conclusion regarding the distribution of stars in other directions in space or such common motions as might be shown, for example, by immense streams of stars circling about the center of the visible universe.

As the measurement of the positions, the motions, the brightness, and the distances of all the stars within the reach of the most powerful telescopes would be a truly Utopian task, Professor Kapteyn wisely limited his efforts, and at the same time provided a means of obtaining the uniformly distributed observations essential to the discussion of his great problem. His simple plan was to divide the entire sky into a series of 206 Selected Areas, thus providing sample regions, uniformly spaced and regularly distributed over the entire celestial sphere. Conclusions based upon the observation of stars in these areas are almost as reliable, so far as large general questions of structure and motion are concerned, as though data were available for all the stars of the visible sidereal universe.

As already remarked, Professor Kapteyn depends entirely

upon the volunteer efforts of coöperating astronomers in various parts of the world. One of these astronomers assumes such a task as the determination of the brightness of the stars, of a certain range of magnitude, in the Selected Areas. Another deals with their positions and motions, another with their velocities measured with the spectroscope, etc. Each observer is able to take a large number of Selected Areas, covering so much of the sky that he may separately discuss the bearing of his results on some important problem, such as the distribution of the stars of each magnitude with reference to the plane of the Galaxy, the motions in space of stars of different spectral types, the velocity and direction of the sun's motion in space, the dependence of a star's velocity upon its mass. Moreover, each observer is free to use his utmost ingenuity in devising and applying new methods and instruments, in increasing the accuracy of his measures, and in adopting improved means of reducing and discussing his observations. He also enjoys the advantage of observing stars for which many data, necessary for his own purposes, have been obtained by other members of the coöperating group. Outside the Selected Areas, such data are usually lacking, because so small a proportion of the total number of stars has been accurately observed.

In physics, as well as in astronomy, there are innumerable opportunities for coöperative research. A good illustration is afforded by the determination of the exact wave-lengths of lines in the spectra of various elements, for use as standards in measuring the relative positions of lines in the spectra of celestial and terrestrial light-sources. This work was initiated in 1904 by the International Union for Coöperation in Solar Research, and is now being continued by the International Astronomical Union. The spectrum of iron contains thousands of lines, many of which are well adapted for use as standards. The work of determining their positions was undertaken by the members of an international committee, in accordance with certain specifications formulated by the Solar Union. But those who took part in the investigation were not bound

by any rigid rule. On the contrary, they were encouraged to make every possible innovation in the manner of attack, in order that obscure sources of error might be discovered and the highest possible accuracy in the final results attained. The outcome demonstrates most conclusively that organized effort and freedom of initiative are by no means incompatible. Important instrumental improvements of many kinds were effected, sources of error previously unsuspected were brought to light, and means of eliminating them were devised. A by-product of the investigation, of great fundamental interest, was the discovery that the peculiar displacements of certain lines in the spectrum of the electric arc, which are greatest near the negative pole, are due to the influence of the electric field. These displacements, previously unsuspected, are sufficient to render such lines wholly unsuitable for use as standards unless rigorous precautions are observed. The international committee, in the light of the new information thus rendered available, will now have no difficulty in completing its task of determining the positions of standard lines with an accuracy formerly unattainable.

The variation of latitude is another subject in which international coöperation has yielded important results. It was found some years ago by astronomical observations that the earth's axis does not maintain a fixed direction in space, but moves in such a way as to cause the earth's pole to describe a small but complicated curve around a mean position. The change in the direction of the axis is so small, however, that the most accurate observations, made simultaneously at different points on the earth, are required to reveal it. These were undertaken at several stations widely distributed in longitude, in Italy, Japan, and the United States. A new photographic method has recently been devised which will probably render unnecessary the use of more than two stations in future work.

An extensive coöperative investigation planned by the Division of Geology and Geography of the National Research Council involves the joint efforts of geologists and chemists in the

study of sediments and sedimentary deposits. This is of great importance in connection with many aspects of geological history, and also because of its bearing on economic problems, such as the origin and identification of deposits or accumulations of coal, oil, gas, phosphates, sodium nitrate, clay, iron, manganese, etc.

The essential requirements are sufficient information on (1) modern sediments and deposits, and (2) changes in sediments after deposition and the causes of such changes.

In the study of sediments now in process of formation it is important to learn the mechanical state and shapes of particles of different sizes, their mineralogical and chemical composition, the arrangements of the material composing the deposit, the source of the material, the transporting agencies, and the cause of precipitation. Modern deposits must be studied in the scores of forms in which they are laid down: in deserts and arid regions and in humid climates, in the beds of great lakes, in the track of glaciers, and in marine beds off the coast, in deltas and bays, or on submarine plateaus, in lagoons, and on reefs in subtropical and tropical waters.

In much of this work chemical investigations are essential, especially on the composition of the waters flowing into the ocean, yielding data on the chemical degradation of the continent and the amount of soluble material discharged into the sea.

In undertaking this extensive investigation, which would include the studies just cited and others on ancient deposits, the following procedure is proposed: (1) To make a more complete survey than has yet been made of the investigations that are at present under way in the United States and Canada. (2) To prepare, in the light of present geological knowledge, a program for the investigations needed to supply an adequate basis for interpreting sediments. As knowledge advances, the program will have to be modified. (3) To canvass the field for existing agencies that are suitable for prosecuting such investigations. (4) To assign problems to those institutions or indi-

viduals prepared properly to prosecute researches of the kind needed. (5) To provide additional agencies for the study of problems of sedimentation and thereby make possible investigations for which there are either no provisions or only inadequate provisions at present.

It is easy to see how an investigator choosing to deal with some aspects of this large general problem would be assisted by information regarding related work planned or in progress, and how readily, as a member of the group, he could render his own researches more widely useful and significant.

Another interesting piece of coöperative research, which involves the joint activities of geographers, physicists, zoölogists, and practical fishermen, is centered largely at the Marine Biological Laboratory at La Jolla, California. Systematic measurements of the temperature of the Pacific near the coast show occasional upwelling of cold water. Simultaneous biological studies reveal a change in the distribution of microscopic organisms with the temperature of the water. This has an immediate practical bearing, because the distribution of the organisms is a dominant factor in the distribution of certain food fishes. The source of the temperature changes, and their influence on meteorological phenomena, are other interesting aspects of this work.

In the field of engineering, the possibilities of coöperative research are unlimited. The fatigue phenomena of metals have been chosen by the Engineering Division of the National Research Council, acting in conjunction with the Engineering Foundation, as the subject of one of many coöperative investigations. Metals and alloys which are subjected to long-repeated stresses frequently break down, especially in aircraft, where the weight of the parts must be reduced to a minimum. The elastic limit and, to a lesser degree, the ultimate strength of steel can be raised by working it cold, provided that a period of rest ensues after cold-working. The tests indicate, however, that increased static strength due to cold-working does not necessarily indicate increased resistance to fatigue under re-

peated stress. In the case of cold-stretched steel, for low stresses the fatigue strength is actually less than for the same steel before stretching.

These phenomena, and others that illustrate the complexity of this problem, afford abundant opportunity for further research. The membership of the committee includes representatives of educational institutions, the Bureau of Standards, and several large industrial establishments. The work was divided among the members, two dealing with its metallographic features, two with machines for testing, two with mechanics of the materials involved, and one with a survey of the subject from the standpoint of the steel manufacturer. The results already obtained promise much for the future success of this undertaking.

Scores of other illustrations of effective coöperation in research might be given, especially in astronomy, where each of the 32 committees of the International Astronomical Union (p. 412 ff.) is constituted for the purpose of organizing coöperative investigations. In spite of the length of this list of committees, it cannot be said that astronomy offers any unique possibilities of joint action. The division of the sky among widely separated observers is only a single means of coöperation, which may be paralleled in geology, paleontology, geography, botany, zoölogy, meteorology, geodesy, terrestrial magnetism and other branches of geophysics, and in many other departments of science. Most of the larger problems of physics and chemistry, though open to study in any laboratory, could be attacked to advantage by coöperating groups. In fact, it may be doubted whether research in any field of science or its applications would not benefit greatly by some form of coöperative attack.

As for the fear of central control, and of interference with personal liberty and individual initiative, which has been entertained by some men of science, it certainly is not warranted by the facts. Coöperative research should always be purely voluntary, and the development of improved methods of obser-

vation and novel modes of procedure, not foreseen in preparing the original scheme, should invariably be encouraged. They may occasionally upset some adopted plan of action, but if the coöperating investigators are following the wrong path, or neglecting easily available means of improving their results, the sooner this is discovered the better for all concerned.

XXIII

THE INTERNATIONAL ORGANIZATION OF RESEARCH

GEORGE ELLERY HALE

THE progress of research, and the rapid advance of knowledge along particular lines, have naturally resulted in the highly specialized organization of science of the present day. Two centuries ago the Royal Society of London and the Paris Academy of Sciences could easily embrace the whole range of science, and include in their membership essentially all of the able investigators of England and France. The establishment of the Linnean Society in 1788 marked the beginning of a dispersive movement that has continued ever since. The Geological Society was instituted in 1807 and the Royal Astronomical Society in 1820, partly as the result of the accumulation of valuable observations too extensive for the Royal Society to publish. One by one the recognized branches of science took definite form, developed a large group of adherents, and a special society resulted. Engineering and medicine experienced the same progress, large general societies being followed by special organizations occupying particular fields. Civil, mechanical, mining, and electrical were the first great subdivisions of engineering, but recent years have brought increased specialization, and we now have societies of naval, illuminating, automotive, and refrigerating engineering, followed within the past year by a society devoted to electric welding. Medicine has also divided into many elements, and it is safe to predict that new special bodies will continue to arise as workers multiply.

This rapid progress of subdivision indicates, of course, a most healthy condition of affairs. Without intense concentration of interest and effort science and its applications could never have attained their present advanced position. Specialization in research, and the association of specialists in groups, must, therefore, be regarded as signs of progress. But the consequences of this movement are not wholly advantageous. The separation of investigators of somewhat different tastes has deprived them of many mutual benefits. In each branch of science instruments and methods are devised to meet particular needs. These may have many applications, direct or indirect, in other quarters, but for the most part they remain the undisputed possession of those acquainted with the special journals in which they are described. How often does the physicist consult the proceedings of a psychological society, or the engineer a journal of physiology? Yet problems often arise in which the experience gained in remote fields would be invaluable. More often, when some large problem is open to attack, its aspects are so various that investigators representing a dozen branches of science may be needed to deal with it effectively. It then appears most clearly how the artificial partition of knowledge, and the erection of barriers between those concerned with its increase and those most interested in its applications, must hamper effort and delay progress.

Without specifying other reasons, it is plain that the increase of specialization, instead of rendering unnecessary organizations dealing with science as a whole, has served to emphasize their possibilities. In fact, it may be doubted whether there was ever a time in the history of science when such bodies could render a greater service. The rise of astrophysics and physical chemistry is evidence enough of the advantage of bridging the gaps between diverging branches, and the great national academies of science are in a position to contribute in large measure toward this end.

In a previous chapter (I) we have seen how the National Academy of Sciences, acting on the approach of war, estab-

lished the National Research Council. The immediate purpose in view was to effect a working federation of research agencies, without regard for the distinctions which have divided them into classes, and kept them from acting together. The organization then effected was a temporary one, designed for war service, and open to reconstruction to meet the needs of peace. In chapter 24 Dr. Angell describes the present organization of the Council and the nature of its work. We may therefore turn to the question of the international organization of science.

The international scientific associations that existed before the war were of several distinct types. Some devoted their efforts to the establishment of uniform standards of measure, others organized coöperative researches, while the majority held occasional congresses for the personal interchange of views. The most important body of the first type is the International Metric Commission, with its International Bureau of Weights and Measures at Sèvres, chiefly concerned with fundamental standards of length and mass. Other bodies of this class dealt with electrical units and standards, the standardization of the nomenclature and ratings of electrical apparatus and machinery, uniformity in the methods of testing materials, annual revision of the tables of atomic weights, annual publication of physical and chemical constants, the science and art of illumination, collaboration in the publication of astronomical ephemerides, uniformity in meteorological observations and their reduction, the determination of standards of wave-length, the classification of stellar spectra, and the unification of time standards.

Men of science interested primarily in coöperative research organized the International Chart of the Heavens, observations to determine the variation of latitude, seismological observations, explorations of the sea, solar observations, studies of the brain, and other investigations. Other international organizations dealt with agricultural information and statistics, physiological instruments, the telegraphic distribution of astronomical information, the preparation of a joint map of the

world on a uniform scale, agreements regarding telegraphy and wireless telegraphy, and the preparation of the International Catalogue of Scientific Literature.

Periodic international congresses, chiefly for the interchange of views, were held in mathematics, chemistry, mining and related subjects, engineering, radio-activity, botany, geology, zoölogy, entomology, ornithology, physiology, anatomy, anthropology, medicine, surgery, cancer research, medical radiology, and geography.

Finally, without attempting to refer to all international scientific and technical organizations, mention should be made of the International Association of Academies, in which most countries were represented by a single leading national Academy, though Germany exercised exceptional influence because of the inclusion of the Academies of Berlin, Göttingen, Leipzig, and Munich.

Many of these international bodies were formed to meet some special need, and they had become so numerous that men of science interested in the larger aspects and relationships of their personal researches were often unable to attend meetings of importance to them. Thus in astronomy independent bodies dealt with the International Chart of the Heavens, solar observations, Kapteyn's Selected Areas, time standards, astronomical ephemerides, distribution of astronomical telegrams, minor planets, and other subjects, and there was no appropriate organization to initiate new projects falling outside of certain limited fields. In chemistry five distinct organizations existed, and yet there was little international coöperation in research. In geophysics separate bodies were concerned with geodesy, meteorology (almost exclusively from the standpoint of official routine), terrestrial magnetism (without real activity), seismology, and other branches of the subject, and there was no means of securing common consideration of major problems embracing several aspects of this extensive science. The Association of Academies was not sufficiently representative of the countries it included, was without permanent headquarters or

adequate funds, had no contact with the great majority of international scientific organizations, and was almost completely inactive between its triennial meetings.

With such considerations in view, the Royal Society called an Inter-Allied Conference on International Scientific Organizations, which opened in London on October 9, 1918. Belgium, Brazil, France, Great Britain, Italy, Japan, Serbia, and the United States were represented by delegates. The first act of the London Conference was to define the attitude of the bodies represented toward the question of future relations with the men of science of the Central Powers. The declaration unanimously adopted pointed out that after the opening of hostilities men of science were still able to hope for an immediate resumption of scientific relations between enemy countries on the conclusion of peace, in harmony with previous experience. Unfortunately, however, the atrocities committed by Germany and her allies have created a new situation in the present war. The work of international scientific associations, unlike business dealings or formal diplomatic procedure, results from personal meetings between friends, who must act together in harmony and personal regard. Such personal relations, especially with the men whose families and acquaintances have suffered such shameless brutality in the invaded countries, are manifestly impossible at present, and they cannot be resumed until Germany and her allies have been readmitted to the concert of civilized nations, and have renounced the political methods which have led to the atrocities that have shocked the civilized world.

No one who is familiar with the nature of international scientific organizations, and has learned by personal visits to the devastated countries something of the feeling of their scientific men, can doubt the necessity of this conclusion. The men of science of these countries cannot be expected to entertain cordial regard toward the invaders, and they unanimously refuse to meet them personally. Those who do not sympathize with this attitude will still be compelled to choose between association

with our Allies or with the Germans. Moreover, even if personal meetings were immediately possible, they would delay rather than hasten the ultimate resumption of friendly relations, because of the bitter arguments that would certainly occur.

Under the circumstances, the Conference decided to recommend withdrawal from former international organizations and the formation of new ones, in which nations that had been neutral in the war would be invited to take part. It was recognized, of course, that some of the old organizations would doubtless be reconstituted and these need not be duplicated. But in other cases, as the illustrations just cited sufficiently indicate, there were important reasons for complete reorganization, notably in astronomy, geophysics, and chemistry. There was also a strong demand for a body with more general functions, to carry out the tasks that the International Association of Academies had failed to perform.

A plan for the establishment of an International Research Council, prepared by the Council of the National Academy of Sciences, was presented to the London Conference by the American delegates. This proposed the organization, by the National Academy of each of the countries represented, of a National Research Council, so constituted as to be a federation of research agencies. The details of organization were to be left to each country, but the general principle of uniting research interests in a single representative body was approved. The International Research Council would then consist of a federation of these National Research Councils.

A second Inter-Allied Conference was held in Paris under the auspices of the Paris Academy of Sciences from November 26 to November 29, 1918. Delegates were present from the countries represented in London, and also from Poland, Portugal, and Roumania. The International Research Council, proposed in the resolutions adopted in London, was provisionally constituted of the delegates attending the Paris Conference, with the understanding that the various National Research Councils, as soon as formed, would take their place in the

federation. An executive committee of five members, representing France, Great Britain, Belgium, Italy, and the United States, was appointed to study in detail the questions presented to the Conference and to undertake other duties, especially those relating to the formation of new international organizations.

Provisional statutes were adopted for an International Astronomical Union and an International Union of Geodesy and Geophysics. Plans for an International Chemical Union were also presented for subsequent consideration and action.

The International Research Council and its associated bodies, the International Astronomical Union, the International Geodetic and Geophysical Union, and the International Union of Pure and Applied Chemistry, were formally inaugurated at the Palais des Académies, Brussels, at a meeting held July 18-28, 1919. Tentative statutes were also adopted for the following bodies, which will be organized as soon as circumstances warrant, and with such modifications as careful consideration may render advisable: International Unions of Mathematics,¹ Physics, Radiotelegraphy, Geography, Geology, Biology and Medicine, and Bibliography.

The objects of the International Research Council, as defined at the Brussels meeting, are :

- (1). To coördinate international activities in the various branches of science and its applications.
- (2). To encourage the formation of international Associations or Unions needed to advance science.
- (3). To guide international scientific activities in fields where no adequate organization exists.
- (4). To establish relations with the governments represented in the Union for the purpose of interesting them in scientific projects.

The General Assembly, consisting of the accredited delegates of the various countries represented in the International Re-

¹ Already in process of organization.

search Council, meets triennially at the permanent headquarters in Brussels. Between meetings the work is conducted by an Executive Committee, now comprising one representative each from France, Great Britain, Italy, Belgium, and the United States, but soon to be enlarged by the addition of other members. In accordance with the plan presented by the National Academy of Sciences to the London Conference, the United States is represented in the International Research Council by its National Research Council.

The International Astronomical Union unites in a single body those who formerly took part in the work of the International Chart of the Heavens, the International Union for Coöperation in Solar Research, the International Union for the Determination of Time and Longitude, International Conferences on Ephemerides, the centralization of astronomical telegrams, and other groups, formally or informally constituted, that dealt with international coöperation in astronomy and its applications.

The objects of the Union are to facilitate international coöperation in research, and to advance the study of all branches of astronomy. Each country represented in the Union organizes a National Committee, preferably in conjunction with its National Research Council, for the purpose of aiding and coördinating its astronomical activities, with special reference to the requirements of international coöperation in research. These Committees also select the delegates to meetings of the International Union.

The range and variety of international activities in astronomy may be illustrated by an enumeration of the coöperative researches and projects already initiated by the Astronomical Union. Thirty-two committees, comprising in their membership the leading investigators of all the countries represented in the Union, have undertaken to deal with the following subjects: relativity; the republication of astronomical classics; notation, units, and economy of publication; coöperation in the publication of nautical almanacs and astronomical ephemerides; abstracts and bibliographies; the distribution of

astronomical telegrams; dynamical astronomy and astronomical tables; meridian circle observations, including the study of atmospheric refraction; optical investigations, both theoretical and applied, relating to astronomical problems and the physical study of instruments; solar radiation; registration of the velocities of solar vapors; the solar atmosphere; expeditions for the observation of eclipses and other astronomical phenomena; standards of wave-length and solar spectrum tables; solar rotation; physical observations of planets; nomenclature of lunar phenomena; determination of longitudes by wireless telegraphy; variation of latitude; minor planets; comets; meteors; the International Chart of the Heavens; stellar parallaxes; stellar photometry; double stars; variable stars; nebulae; classification of stellar spectra; stellar radial velocities; time standards and determinations; and the reform of the calendar. This bare enumeration can give little conception of the importance of the work of the Astronomical Union, but if it were feasible in the available space to outline the work of some of these committees, and to indicate the advantages that must result from a combined attack on astronomical problems, in which the ablest investigators will utilize the instrumental resources of scores of great observatories in accordance with a general plan of operations, the true possibilities of such united effort would become obvious.

The scope of the International Union of Geodesy and Geophysics is no less comprehensive. Its objects are to encourage the study of problems relating to the figure and physics of the earth, to initiate and coördinate investigations requiring the coöperation of several countries, and to facilitate special investigations, such as the inter-comparison of instruments. The Union is constituted of six Sections, dealing with (1) Geodesy, (2) Seismology, (3) Meteorology, (4) Terrestrial Magnetism and Electricity, (5) Physical Oceanography, (6) Volcanology. Each of these Sections appoints special international committees, similar to those of the Astronomical Union,

to organize coöperative researches in their respective fields. Action has necessarily been delayed in some of the Sections, but a preliminary list of projects already initiated by the Section of Terrestrial Magnetism and Electricity will serve to indicate the character of the coöperative work to be undertaken in this branch of the Union. These involve the comparison of the magnetic instruments in use in different countries, and the determination of the best method of measuring the magnetic elements in absolute units; the study of atmospheric electricity by a joint committee of the Section of Meteorology and the Section of Terrestrial Magnetism and Electricity; coöperation with the proposed International Union of Scientific Radio-Telegraphy in the investigation of the electric phenomena of the higher atmosphere; the systematic exchange of magnetic curves; the appointment from time to time of special committees to investigate and report on specific problems in the field of the Section; and coöperation with the International Astronomical Union in investigating the relationships between solar and terrestrial magnetic and electrical phenomena.

The American branch of the International Union of Geodesy and Geophysics was organized by the Division of Physical Sciences of the National Research Council. Out of this has grown the American Geophysical Union, which officially represents the United States in the International Union and retains organic connection with the Division of Physical Sciences.

The rapid development of chemistry in recent years, and the limitless variety of its applications in the arts have led to a great advance in the public appreciation of this branch of science. The possibilities of international coöperation in chemical research are at least as great as in astronomy and geophysics, but prior to the war only a beginning had been made in utilizing them. The organization of the International Union of Pure and Applied Chemistry, in which the United States is represented by the Division of Chemistry and Chemical Technology of the National Research Council, supplies the means

of securing the coöperation of chemists engaged both in fundamental investigations and in industrial research.

The objects of this Union are to provide for permanent coöperation between the chemical societies of the nations represented, to coördinate their scientific and technical procedure, and to contribute to the advancement of chemistry in all of its aspects.

The first task to be undertaken by authority of this Union will be the preparation and publication, under American auspices, of a critical compendium of physical and chemical constants, as part of the contribution of the United States toward an international program of documentation which will be developed as rapidly as possible. The National Research Council, with the support of the American Chemical Society and other national societies, has been requested to organize the editorial board and secure funds for this large project, which will naturally involve considerable expense. This board, while charged with complete responsibility, will conduct the work on an international basis, with the aid of assistant editors and collaborators in the principal nations of the International Union. Other large coöperative projects will be taken up later.

The International Research Council provides the long-desired means of coördinating the activities of international scientific bodies, which in the past have almost invariably worked independently — a condition no longer possible if real efficiency is to be expected. Similar confusion has prevailed in each of the participating countries, where no agency has existed to bring together men engaged in different classes of international research. In the United States this difficulty has been overcome by the organization of the Division of Foreign Relations of the National Research Council. This division, the organization of which is more fully described on page 424, acts for the National Research Council in dealings with the International Research Council, promotes coöperation in matters of common interest between the American National Committees or other

national representatives of international organizations, aids in the initiation of new international unions, keeps the State Department in touch with pending scientific and technical questions in which the Government may be interested, and publishes annual summaries of international activities in science and technology.

If space permitted, it would be interesting to survey the work of other important international organizations in which the United States takes a prominent part, such as the International Electrotechnical Commission, the International Conference on Electrical Units and Standards, the International Commission of Illumination, and of such bodies as the National Research Council Committee on Pacific Exploration, whose projects are of international scale. Since it is manifestly impossible, however, to cover such extensive ground, this chapter has been confined to a sketch of some developments resulting from the war which have led to a new and promising unification of research activities, in harmony with the spirit of the times.

XXIV

THE NATIONAL RESEARCH COUNCIL

JAMES R. ANGELL ✓

UNTIL the organization of the National Research Council, scientific research in the United States had been carried on by a group of agencies working for the most part in independence of one another. Research in pure science has been chiefly cultivated in the universities and in a small group of privately endowed research institutes. The scientific bureaus of the Federal Government and certain of the scientific agencies of the several states have from time to time devoted themselves to investigations in this field; but in the main, they have almost inevitably been monopolized by problems of applied science possessing the urgency of pressing practical necessity. The sum total of the scientific work carried on by these state and federal agencies (e. g., the federal Department of Agriculture, the state experiment stations, state geological surveys, etc.) has been very large, and its significance for the welfare of the public has been of the highest consequence. The research aspects of applied science have also been represented to some extent in the industrial laboratories of the country, certain of which have been developed to a very high degree of efficiency, although the number of such laboratories is lamentably small when compared with the need and the opportunity.

Merely to state the foregoing facts is to suggest the valid conclusion that the best results in research can never accrue under conditions so lacking in unity and coherence of purpose. The National Research Council, created by the relentless pressure of the war, is endeavoring to secure in times of peace the

close coöperation, both in the planning and execution of research, requisite to bring to the nation the largest possible rewards from scientific investigation. Clearly, there are other methods than those represented by the Research Council whereby to achieve these desired ends, and a few words of comment may serve to exhibit the considerations which have justified the course pursued.

The policy adopted by certain other countries, notably Great Britain, Japan, Italy, the Dominions of Australia and Canada, might with modifications have been imitated. In this case, research in its largest bearings would be made dependent upon the control and financial support of the Federal Government, which might create its own agencies through which to work or might allot subventions for purposes of research to extant organizations, whether directly under Government control or not. Assuming that Congressional appropriations might be secured in necessary amounts, this type of plan might be expected to produce results upon a large scale more rapidly than any other, but experience has shown that under the actual conditions in the United States, direct federal supervision of scientific work is likely to carry with it substantial limitations which would in the long run seriously reduce the efficiency of research.

Another possible method would be the creation through private benefactions of a colossal endowment to be administered like certain of the present research institutes. The great difficulty here is the magnitude of the capital required to cover so wide a field as is represented by the National Research Council. The institutes referred to follow as a rule only a single branch of work. On the other hand, the Council as a federation of scientific agencies would be free from the objection sometimes urged against these research foundations, i.e., that they are purely private organizations, and as such, are likely to be autocratic and arbitrary in their methods.

In its present organization, the National Research Council represents the attempt to accomplish in a democracy, and by

democratic methods, results of the most lasting national benefit in the field of research in pure and applied science. For reasons of the kind indicated above, it has not been thought advisable to make it directly dependent upon the Government, although it does enjoy an important measure of Government recognition through its Government Division, through its contact with the State Department, explained at a later point, and through its relation to the National Academy of Sciences, which possesses a federal charter, and which by the Executive Order of President Wilson on May 11, 1918, created the Council as an official agency of the Academy. The Council has achieved its democratic element by arranging that its membership shall be controlled by the great scientific societies, of which upwards of forty are now represented in its constituency. These societies elect to the scientific and technical Divisions of the Council a majority of their representatives, and these representatives in turn select the administrative officers who shall direct the actual scientific enterprises which the Divisions undertake. These directing officers, known as Chairmen, receive salaries from funds of the Council which have been secured by private benefactions, and serve normally for one year at a time with residence in Washington.

Following the traditions of the National Academy of Sciences, the field of work of the National Research Council has for the present been restricted to the physical and natural sciences. The lines which divide the sciences from one another in any generation are necessarily somewhat arbitrary, and the organization of the Council reflects something of this arbitrary character. There are accordingly seven sub-divisions devoted to the following groups of sciences: (1) the physical sciences, including physics, mathematics, and astronomy; (2) engineering in all its branches; (3) chemistry and chemical technology; (4) geology and geography; (5) the medical sciences (both the clinical aspects and those of the underlying pure sciences); (6) biology and agriculture; (7) anthropology and psychology. These groups may be conceived as furnishing the foundations

upon which the great mass of the research interests of the Council is based. They also represent the vast preponderance of the personnel operating through the Council, for it is upon the membership of the scientific and technical societies that the Council is ultimately grounded, as has been explained in an earlier paragraph.

The informed reader will observe that these Divisions relate in part to the pure sciences; physics, chemistry, mathematics are cases in point. In part, however, they reflect the interests of applied science, as in the case of engineering, of chemical technology, and to some extent each of the other Divisions. The distinction between pure and applied science is one which has been frequently debated, and upon which substantial diversity of opinion is still entertained. But from the point of view of the conception upon which the work of the Council is actually administered, this distinction may be regarded as almost wholly psychological in character. The worker in pure science is seeking primarily to enlarge the field of knowledge, and to gratify his own intellectual curiosities, whereas the worker in applied science has as his motive the solution of some concrete practical problem. Both men are scientists, and both may be engaged in *bona fide* research of the utmost importance.

Despite the fact that the distinction just mentioned is from the theoretical point of view of relatively secondary consequence, its practical aspects give it great significance, and this fact has been explicitly recognized in the organization of the Council, as will be pointed out in a moment.

In view of the exposition in the opening paragraphs of the actual extant conditions surrounding scientific research in this country, it will be readily appreciated that the scientific work of the Divisions already described must be intelligently related to a considerable group of interests and agencies. To accomplish these results, the Council has established a group of six so-called General Divisions designed to meet this need.

1. *Government Division.* In the first place, it is highly es-

sential that the Council should operate in the closest possible contact with the scientific agencies of the Federal Government. Not only because of the magnitude and variety of the enterprises conducted by government scientists, but also because of the close connection thus afforded with issues of crucial moment for the public welfare. It is quite indispensable, if the Council is to achieve its intrinsic purposes, that it should be kept in intimate relations with all this work. To achieve this end, the so-called Government Division has been formed, upon which, by appointment of the President of the United States, are representatives of each of the scientific and educational bureaus of the federal service. These include not only such scientific groups as are represented by the Bureau of Standards of the Department of Commerce and the Bureau of Chemistry of the Department of Agriculture, but also the scientific and technical services of the army and navy.

The constituency of this Division at the present moment is made up of forty-one members. Several beneficial results are hoped for from the work of the Division. As indicated above, it will serve as a liaison agency to keep the several Divisions of the Council in touch with the scientific work which is being done by the Government. It will also afford opportunity for the converse of these advantages in bringing constantly before the notice of representatives of the Government the more important scientific projects which are going forward under other auspices both in this country and abroad. Finally, it is believed that the Division may serve to perpetuate and develop a full and frank coöperation among the scientific forces of the Government, such as was successfully initiated by the Council during the war, but which prior to that time had not generally existed. Moreover, it may be hoped to offer a channel through which coöperative enterprises may be launched. These may affect either the relations among the Government bureaus themselves, or the relations of these bureaus to outside scientific agencies with which they have not hitherto been in active contact. There is, in other words, obvious opportunity for

team-play which has not up to this time been at all fully developed. Incidentally, it seems not too much to hope that a fuller knowledge among representatives of the scientific bureaus of the Government, each regarding the work of the others, may exercise a highly beneficial influence in discouraging radical and inexpedient legislative action such as has been more than once threatened in the ill-informed attempt to avoid duplication of government work where only the appearance and not the fact of such duplication is involved.

2. *Foreign Relations Division.* For many years past there have been international organizations of a scientific character, certain of which have enjoyed the official recognition and support of the Government, others of which have been conducted independently of any such support. It appears at once, upon the most superficial inspection, that certain types of scientific problems can only be effectively attacked by international co-operation. Astronomy, seismology, and meteorology afford abundant instances of such problems. Prior to the Great War, various international scientific unions had been developed, some of which conducted extensive coöperative researches. These organizations were inevitably shattered by the effects of the war, and to take their place, there was created at Brussels in July, 1919, an International Research Council, composed of representatives of the Allied powers. To this organization several of the neutral countries have already declared adherence, and in due time it may be expected that the Central Powers will also be admitted.

In the establishment of this International Research Council, our own Council exercised a large measure of initiative, and with the establishment of the new organization, the national council has become its official American representative. Complete details of the international organization are still in process of development, but in general, the plan involves a series of constituent unions, e. g., astronomy, mathematics, biology, chemistry, etc., as described by Dr. Hale in Chapter XXIII.

To the Foreign Relations Division of the National Research

Council is confided responsibility for the administration of the joint international interests of the several American organizations represented in the International Council, and also the supervision of any other desirable international scientific matters. A representative of the State Department (at the moment, the Honorable William Phillips) acts as one of the vice-presidents of the Division, and thus assures organic contact with the affairs of that Department. The Division as at present constituted includes the President and Foreign Secretary of the National Academy of Sciences; the President or other representative of the American Association for the Advancement of Science, of the American Philosophical Society, and of the American Academy of Arts and Sciences; representatives of the Department of State; representatives of the leading international scientific and technical organizations in which the United States participates; certain officials of the National Research Council; and a group of members at large, chosen for their nationally representative qualities.

The work of this Division is not only of signal consequence from the strictly scientific point of view, it is also pregnant of political consequences of prime importance, for nowhere are sympathetic and appreciative international relations so easily cultivated as in the realm of science. How sorely the new world stands in need of such friendly bonds is already painfully apparent.

3. *States Relations Division.* In many states of the Union there are important scientific and technical activities under state control, dealing with geology, public health, fisheries, forestry, and other subjects. During the war the formation of State Councils of Defense brought representatives of such agencies into groups, comprising also representatives of educational and other institutions. In some instances, of which California affords a notable illustration, very efficient Research Committees thus resulted, which dealt successfully with war problems arising locally or making demands upon the natural resources or agencies of the State in question. Some of these committees

have been perpetuated, and in other instances similar committees are to be formed. The Division of States Relations of the Research Council, which began its work during the war, has now been permanently established with the following functions:

1. To obtain information as to the most effective types of organization which may represent the group of departments concerned with research within a state government. The method by which these groups can be brought together may not be the same in all cases. This has been done by a central committee in California, and in part by a Board of Natural Resources and Conservation in Illinois. Still other variations of method may be expected in accomplishing this coördination in other states.

2. To obtain an acquaintance with the best methods of co-operation between the departments of the state government and the institutions within the state,—educational, commercial, industrial, and governmental,—which are concerned with research. Close connection between the work of the Division of States Relations and the Division of Educational Relations will be essential, as educational institutions are important centers for research work.

3. To consider the most effective methods of research co-operation between states, and to study also the problem of the relations between the scientific agencies of the states and those of the Federal Government.

The success of the work of this Division will necessarily be in large degree contingent upon the response of the scientific and political authorities of the several states. The Council is in no position to employ any coercion in the matter, and if it were, would not desire to do so. The response, however, which has already been accorded to the suggestion that the States Relations Division should exercise the functions mentioned has been very cordial and very wide-spread. There is unquestionably a general recognition of the need for some disinterested and competent agency to meet the purposes described, and it seems reasonable to hope that substantial as-

sistance may be rendered the individuals and agencies concerned in their attempts to serve the public welfare in the most effective manner.

The present membership of the Division comprises, in addition to representatives of the several other Divisions of the National Research Council and certain groups of representatives chosen at large, six regional representatives of state research committees and representatives from organizations particularly concerned with state research problems, to wit, the Association of American State Geologists, the Society of American Foresters, the American Association of State Highway Officials, and the International Association of Game, Fish, and Conservation Commissioners.

4. *Educational Relations Division.* The institutions of higher learning in the United States represent two important groups of research interests. In the first place, a considerable proportion of the research in pure science is carried on in these institutions; and in the second place, they are the sole sources from which there is to be derived trained personnel for advanced scientific work. It is obvious that as in the case of the other Divisions of General Relations, the several Divisions of Science and Technology, mentioned earlier in the chapter, sustain the most intimate affiliations with the Division of Educational Relations, representing the educational institutions. Even during the war, therefore, a definite effort was made to organize the research interests in these educational institutions; and the peace-time organization of the Council has seen in this field one of its largest opportunities, and one of its most pressing obligations. Again, as in the case of the work of the States Relation Division, there is and can be no question of a coercive attitude on the part of the Council. It stands to these institutions purely in the relation of a would-be helper, unselfishly devoted to the development in them of the best conditions for productive research and the training of research men. The Division has initiated its work by a careful study of the facilities for research work in the major institutions of the

country. It is hoped on the basis of the results of this study that it may be possible to suggest methods of improving facilities for research and its conduct.

To mention but a single point illustrative of the possibilities in this direction, attention may be called to the present entire lack of coöperation and mutual understanding among the universities of the country regarding the development of research facilities, both in equipment and in personnel. At present, it may be said to be the common ambition among the stronger universities to develop research in practically every direction of science. This policy, if continued unmodified, is bound to lead to the most wasteful expenditure by the needless duplication of costly plants and the multiplication of personnel, considerable portions of which will necessarily be of inferior quality. While in some branches of science, it may for a long time to come be difficult to produce the necessary number of trained research workers, and while in these cases multiplication of facilities is not likely to be wholly unwarranted, there are many lines of scientific work in which a small number of institutions would be entirely adequate to produce the necessary personnel, and to carry forward a justifiable amount of scientific research. Only on the basis, however, of some mutual understanding among the authorities of these institutions can it be hoped that a saner and a more judicious program can be adopted. It is not altogether Utopian to hope that the National Research Council may be of assistance in focusing public opinion upon this issue, and in stimulating definite and progressive action. Unlike most of the other agencies concerned, the Council occupies an entirely disinterested attitude, and is in a position to assist in deciding upon the intrinsic merits of the case.

In addition to certain members chosen at large to represent a broad diversity of interests and certain representatives of other Divisions of the Council, the Division is at present composed of representatives of the following associations, i. e., the Association of American Colleges, the National Association of

State Universities, the Association of American Universities, and the American Association of University Professors.

5. *Division of Research Extension.* There is something of a paradox in the fact that despite the reputation of the United States for fertility in mechanical inventiveness, the substantial productivity of the country, in what may be seriously entitled scientific industrial research, has with the exception of a few industries been conspicuously small. The experiences of the war brought out with a vividness nothing else could have done the backwardness of the country in this field of industrial research. Whether the high tariff walls which have generally existed to protect our industries, or the fact that we have had an adequate outlet for our industrial energies in our own national commerce, had concealed the real conditions, it remains true that the fact of our backwardness had been screened from general public recognition. Nothing is more certain, however, than that if we expect to gain and retain our fair share of the control of foreign markets, especially as regards Germany and Great Britain, we must arouse to the necessity of basing our great scientific industries more fully than heretofore upon sound scientific foundations. We must also appreciate the fact that to keep them abreast of the times, we must make persistent use of scientific research. Recognizing the urgency of this general situation, the National Research Council has established a special Division (originally called the Division of Industrial Relations, but now known as the Division of Research Extension), devoted to the promotion of a wider appreciation of the true facts of the case and to the stimulation among the industries, wherever possible, of active research enterprises.

The problem here subdivides somewhat naturally into two main issues. There is, on the one hand, the case of the great corporations controlling one or more of the large essential industries; and there is, on the other hand, the case of the small manufacturer who may or may not be engaged in an industry already occupied by dominating corporations. In the first case, the problem is one of persuading the directors of these larger

concerns to put into their organization program provision for adequate research laboratories and personnel. It might be supposed that the purely selfish interests of such organizations would already have led them to go as far in this direction as current industrial circumstances warrant. There are not a few conspicuous instances in which this is true. But there are many others in which for various reasons a fundamental unwillingness to encourage the establishment of research organizations is deeply ingrained. Among these reasons ranks high a not altogether intelligent conservatism; and the dread of being obliged to discard extant equipment and methods, despite the possibly increased profits, also figures conspicuously. Certainly from the point of view of public welfare and the national position in times of peril, it is highly desirable to induce these industries to adopt an enlightened and generous policy of research.

The case of the small producer is quite different. It is out of the question for him to establish a laboratory on any scale which is likely to promise justification in terms of immediate financial return. There is, however, no reason why he should not combine with other small manufacturers in his own line of work to finance investigations of a kind directly beneficial to himself and his colleagues. This plan has actually been tried both in this country and abroad, and with very considerable success. The Research Extension Division of the Council has had the good fortune to be a prime mover in a number of projects of this general type, and while the specific details are likely to vary, in view of the peculiar conditions met with in the different industries, the general principle of coöperative work has apparently come to stay.

Not the least interesting of the developments which are to be hoped for from this stimulation of industrial research is a recognition on the part of the industries of their obligations to the discoveries of pure science, which in every case underlie successful improvements in industrial practice. It seems hardly too much to believe that in the not remote future this

obligation will be recognized in the form of permanent annual contributions to the institutions and individuals competent to carry on fundamental research in pure science. For while it is never possible to predict at just what point a discovery in pure science may assume practical significance of a large kind, it is abundantly demonstrated that only through such discoveries are essential improvements in scientific technique to be obtained, and no investment of financial resources is so likely in the long run to be productive of fundamental improvement in the conditions of human life. While such an investment of money is in a certain sense philanthropic or often speculative, it is in the long run an investment more certain than any other to be productive of the highest values which can be obtained by human ingenuity.

6. *Research Information Service.* Despite the careful study given in recent years to the general problems of bibliography, it is still true that for many of the purposes of scientific research, the present available resources for the prompt securing of essential information are lamentably defective. The intricacies of modern science have produced a situation in which accurate and exhaustive knowledge of the scientist's own special field frequently is insufficient to serve his purposes. Again and again it becomes necessary for him to secure quickly and accurately information from other cognate fields of science, and in such instances the present machinery for the speedy attainment of reliable information is extremely unsatisfactory.

This description, which applies conspicuously in the field of pure science, is even more significant in the ranges of applied science in the industries. Many of the industries have felt this need, and have made sporadic efforts to meet it. The engineering fraternity has also made a beginning at the maintenance of a bureau to supply certain types of information, but all these efforts are thus far of a fragmentary and non-comprehensive character. The Germans had built up at Grosslichterfelde a great organization to meet precisely these needs, and had achieved signal success in their undertaking. It is our

intention to surpass, if possible, the merits of that institution. The success which was attained during the war in establishing certain features of this Information Service, reference to which will be found in Chapter 3, encourages us to believe that our dream may come true, and that an effective organization can be developed to meet the necessities in times of peace.

Without attempting to portray in minute detail the several aspects of the work of this Division as it is now planned, a brief description may be offered.

- (a) Provision will be made for a catalogue of research laboratories, and already we have a list of such covering approximately 5000 entries. This catalogue includes both laboratories devoted to pure science and those dealing with industrial activities. In addition to the name and address of the organization, there will be given the name of the director, the personnel of the staff, the chief lines of research pursued, the space available, the approximate annual expenditure, and in short, all information necessary to give a clear picture of the type of the work which the laboratory may be expected to be competent to undertake.
- (b) A catalogue of current investigations will be developed. The idea of rendering available information regarding current research is decidedly novel, and at first sight, is likely to be thought impracticable. There is no doubt that the possibilities of the plan vary very widely in the different fields of science and in the different industries; but there is also no question that in certain fields it is entirely practicable, and that wherever it can be brought about, it is sure to possess high value. So long as scientific investigation is carried on in a purely individualistic way, and surrounded with the atmosphere of the trade secret, such a project has, of course, no status. Not only are the possibilities of coöperative research becoming rapidly more widely appreciated, but there is also an

increasing recognition of the extent to which scientific men can be of assistance to one another by frank and full interchange of knowledge regarding current work. At present, there is no central agency which can serve as an exchange for such information. The saving of time and expense represented by the ability to draw upon such a source of knowledge can hardly be overestimated. It pre-supposes on the part of the individual investigator not only the willingness to make periodic communication regarding his own work, but also the willingness to take the small amount of time necessary to fill out the enquiry cards which must inevitably be used if the information supplied is to be rendered promptly and easily available to others.

Naturally the industrial laboratories working on problems which directly affect their competitive relationships will not find it possible to participate very fully in this type of interchange of information. In so far, however, as work which they carry on has significant relations to the issues of fundamental science, there is reason to believe that they too will be willing to coöperate in this program.

- (c) There is in preparation a catalogue of research personnel which when complete will supply full and accurate information regarding the professional equipment and accomplishments of all scientific research men, with their addresses. The Research Information Service has already received so many important enquiries covering this field as to make it clear that there is a very genuine need for information of this character. If a university or industrial concern desires a competent research man in a special field, there is at present no means of getting the necessary information save by slow correspondence with a considerable group of individuals or agencies, where the information may or may not be actually available. It is hardly necessary to argue the utility of a

service of the proposed type. The labor of preparing the data in an accurate way, and the difficulties of keeping it up to date, are obvious, but they are in no sense insuperable.

- (d) It is planned to develop a library of sources of research information. This would include bibliographies, systematic abstracts, digests, hand books, and other convenient periodical or special sources of information concerning research. There has already been prepared as a preliminary step a catalogue of bibliographic and abstract periodicals of the world.
- (e) For the use of the several Divisions of the Council, there has been prepared a catalogue of scientific and technical societies with information concerning the time and place of meeting.
- (f) An index of approximately 12,000 cards has been prepared, covering all foreign reports received by the Research Information Service.
- (g) A plan has been devised for improving the status of scientific publications, and especially for rendering abstracting and the construction of hand books more satisfactory. It involves coöperation with the several Divisions of the Council in the conduct of systematic enquiry concerning the status of publications in special fields and possible methods of improvement.

With respect to bibliographic listing and abstracting the following features of the general plan deserve remark:

- (1) Formulation of carefully considered and thoroughly tested rules for the preparation of abstracts in any given field of science. The inadequacy of indices is due chiefly to the fact that the title of an article is assumed to be an accurate and complete guide to its contents, which is very rarely the case. It is highly desirable, therefore, that a system be devised which will present in the briefest and most precise

form the actual significant contributions in a paper regardless of its title.

- (2) The editorial requirement that a suitable abstract prepared in accordance with these rules be submitted with a manuscript when offered for publication.
- (3) That this author's abstract, after proper editing, be published in a periodical abstract journal (possibly monthly) for the appropriate science.
- (4) That all abstracts be held in type for at least one year, in order that the materials may be reclassified according to subject and reprinted as an annual topical review.
- (5) That as essential parts of this annual topical review for any given field of science, there be also published complete author and subject lists.
- (6) That such lists be accumulated and published in separate volumes at intervals of five or ten years.

The ideal execution of this general plan will demand international coöperation by developing methods, and by the assistance of special scientific groups, to establish suitable abstract or other periodicals. As a matter of fact, encouraging progress has already been made with several of the more important scientific journals which have adopted the substance of the proposals involved in this program.

- (h) Although this Division is in no sense primarily responsible for the publication policies of the Council, it has contributed substantially to their development. These policies involve the publication in a bulletin series of important scientific papers which do not find any natural place in extant scientific journals, and also the circulation of reprints of important papers published in media reaching but a limited circle of readers. Already there have appeared several reprints and the following bulletins: Number 1, "The National Importance of

Scientific and Industrial Research," by George Ellery Hale and others; Number 2, "Research Laboratories in Industrial Establishments of the United States of America," compiled by Alfred D. Flinn; and Number 3, "Periodical Bibliographies and Abstracts for the Scientific and Technological Journals of the World," compiled by R. Cobb. It may be added in this general connection that the Proceedings of the National Academy of Sciences constitute the official organ of the National Research Council, and that in addition to the record of the Council's transactions, there are here published certain of its scientific contributions, including reports of its more important committees.

* * * * *

It is out of the question within the limits of space available to enter in any complete way upon the work of the seven Divisions of Science and Technology, mentioned in the opening paragraphs of this chapter. Including, as these do, the interests of physics, mathematics, astronomy, geodesy, meteorology, seismology, vulcanology, engineering in all its branches, chemistry and chemical technology, geology and geography, the medical sciences, zoölogy, botany, and agriculture, anthropology and psychology, it would obviously be impracticable to attempt any detailed description of the scientific research work which is being developed. Two considerations, however, deserve explicit emphasis.

In the first place, these Divisions are composed of scientific men, selected by their peers for their reputation as competent investigators in their several fields of work. These groups come together and discuss with exhaustive detail the most urgent needs in their own research fields and the most practicable methods of meeting these. The projects which they then decide upon as deserving immediate attention represent the most mature and well-considered opinions of the men best qualified to judge. In this sense the projects to which the

Council commits itself are based upon a scientific consensus of opinion such as has never before been available in this country.

The second consideration, and one of perhaps equal importance, is that the Council in its effort to stimulate and promote research has found one of its largest fields in the development of coöperative research enterprises, for which there has also been hitherto no adequate national provision. This coöperation may occur as between individual scientists working in the same field, for example, physics or chemistry, as between scientists in different fields, as between research organizations like universities and government bureaus, as between state agencies or state and federal agencies, and finally, as between the consumers, so to speak, of research represented by the interests of commerce and industry. Every one of the great fundamental problems confronting modern society leads out in the effort to solve it into a large group of related but often distinct sciences. For example, the problem of fuels is in part one of chemistry, in part one of geology, in some portions of the world one of forestry, in part one of transportation, etc. Food production, distribution, and consumption similarly involve a wide range of scientific problems, partly zoölogical, partly botanical and agricultural, partly chemical, partly bacteriological, etc.

\ The organization of the Council is peculiarly adapted to permit the easy assemblage of groups of competent scientists to deal with such fundamental issues as these, with which no single government agency and no other single scientific agency is at the moment at all competent to cope. One or two illustrations of the kind of thing the scientific Divisions of the Council are attempting to accomplish may be permitted.

We may take one instance from the field of coöperation among scientists and one from that of coöperation among the users of scientific research in the industries. The cases are chosen to exhibit the possibilities of coöperation, because it is at that point that our present national organization of research is most defective, and the need for an agency such as the

Council most conspicuous. During the war, the Council was able to bring about a large number of coöperative research undertakings, but these were mainly represented by the appointment of committees, each of whose members was a specialist in the same scientific field, and they worked together by dividing the problem and allocating its several phases to one or another of their members. This is a highly profitable form of procedure where time is of crucial importance, as in war, but it is less likely to commend itself to scientists in time of peace. Meantime, there are abundant problems, and among them many of fundamental national importance, which can only be solved coöperatively and by the joint action of specialists representing quite diverse scientific interests.

The Division of Biology and Agriculture has created a committee for the study of the problems of food and nutrition. The general field of work has been subdivided into that of human nutrition and of animal nutrition. A group of some fifteen eminent scientists have come together and made a preparatory survey of the general problem. These scientists represent chemistry, physiology, zoölogy, physiological and biological chemistry, vital statistics, agriculture, animal husbandry, and household economics. If, as their work develops, need arises, they will take in representatives of other branches of science. The war made it quite plain that there is a problem of national nutrition quite distinct from that of merely individual nutrition, and to this the committee will also give attention. It will at best be several years before the full fruits of this work will begin to come in, but the coercive and essentially practical character of the problem is evident the moment one faces the facts, and particularly in our own country, where the preparation of large parts of the food material of the people is in the hands of a few great industries. The old-fashioned community lived mainly upon its own immediate neighborhood. The modern community puts under contribution for its food the remotest corners of the earth. The committee has already made an excellent beginning in its work, the cost of which will

probably be largely met by the more directly interested industrial concerns.

The Institute of Baking may serve to illustrate coöperation among the consumers of research. The big industrial concern can often afford to establish its own research laboratory, and many instances of such procedure might be cited. But the small manufacturer cannot afford this luxury, and he must either go without it or join with other small concerns to establish a coöperative research enterprise. The National Research Council has been carrying on an active campaign to introduce the formation of such coöperative arrangements in a considerable group of industries, and thus far with very encouraging success. The Institute of Baking is one in which the Council, through its Research Extension Division, has had some part.

The Institute has secured the use of an admirably equipped laboratory, has engaged a scientific director, who has entered into advisory relations with the Council, where he can command suggestions from the ablest men in the country in the various problems of physics, chemistry, bacteriology, etc., involved in the industry. The 28,000 members of the baking trade in this country will be the direct beneficiaries of this work, and indirectly the entire community will profit by it.

Many other instances of research work inaugurated by the Divisions of Science and Technology might be adduced, but these must suffice, and may serve to convey some impression of the character of their activities.

Through its system of publications, to which reference has already been made, the Council attempts to give some publicity to its own work and to the scientific results which accrue from it, although the extant agencies for scientific publication will no doubt care for the larger part of such requirements. In addition, however, to this attempt to bring its work before the public, the Council has entered upon a system of exhibits, which deserves brief mention.

In a new building, which will serve as a permanent home for the National Academy of Sciences as well as for the Council,

there will be certain permanent exhibits of fundamental scientific interest, but perhaps more significant will be the system of rotating exhibits designed to show the latest discoveries in pure and applied science in ways readily intelligible to the general public. These exhibits will then be shown in other large centers throughout the country wherever satisfactory arrangements can be made. At the present moment, there is being shown a most striking exhibit of the wireless telephone and of the essential discoveries in pure science which have led up to its perfection. This exhibit has been prepared by the American Bell Telephone and Telegraph Company and the Western Electric Company, with assistance from the Signal Corps of the army.

It is hoped by these methods to arouse a much deeper and more widely disseminated public appreciation of the progress which is constantly going on in scientific work, and of the significance of this work for the prosperity of the commonwealth. If the Council can accomplish some fraction of the general purposes which have been outlined in this chapter, it may well feel that it has served its purpose. Its organization is plastic, and can be made to conform to the changing needs of successive generations. It is based upon an unselfish devotion to the development of human welfare through the most energetic prosecution of the resources of science.

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